Fishery, Reproductive Biology, Feeding & Growth of the Snook (SPHYRAENIDAE: *Sphyraena novaehollandiae*) in South Australia

Final Report to the

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by

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ABSTRACT

The reproductive biology of *Sphyraena novaehollandiae* was studied in South Australia by fortnightly sampling of commercial catches, over 12 months with 955 specimens collected. The spawning season of late November to early February was determined, as well as the sex ratio of catches. Size at first maturity was 40 cm and 42 cm total length for males and females respectively. Mean fecundity, GSI and Condition Index was also determined. The feeding habits was investigated by the examination of stomach contents, and indicated that the species is an opportunistic feeder.

Growth was determined by modal progression analysis of length frequency data using ELEFAN I and Wetherall Plots, and the von Bertalanffy growth parameters estimated an L_∞ of 89.9 cm for males and 98.0 cm total lengths for females. Sexes combined resulted in an L_∞ of 97.4 cm using ELEFAN, and 98.6 cm total lengths using the Wetherall method.

Otoliths growth increments using whole and transversely sectioned otoliths were studied to validate the length frequency analysis, and the L_∞ results for combined sexes and females were 103.0 and 96.7 cm total lengths respectively. The length weight relationship for males was W: 0.0016 $L^{3.21}$, females W: 0.0020 $L^{3.13}$, and for unsexed juveniles/pre-adults W: 0.0021 $L^{3.14}$.

The instantaneous total mortality (Z) for both sexes was estimated using length-converted catch curves, and these were 0.79 and 0.72 for the males and females respectively and 0.73 for total specimens.

Methods and Catch and Effort of the fishery was also determined.

Detailed copies of this Report (M Sc thesis) can be found at the Australian Maritime College library, Launceston, Tasmania, and the SARDI library, Adelaide, South Australia.

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1. INTRODUCTION

1.1 Background

Commercial fishing for snook *(Sphyraena novaehollandiae)* in South Australian is concentrated in coastal waters of less than 10 m depth. Snook, also known as the short-finned seapike (Figure 1) are common in South Australian waters throughout the year, and is an important inshore commercial species. 124 tonne live weight was landed in 1992/93 using haul nets and trolling gears, with a market value of $263,000 (SARDI, Aquatic Sciences, pers. comm. 1993). An unknown quantity is also landed by recreational fishers usually by trolling, snook being the 5th most landed species taken by recreational small boats in 1990 (Jones and Retallick, 1990).

There is a worldwide lack of biological and taxonomic data for the Sphyraenids (De Sylva, 1973; Migdalski & Fichter, 1976; Myers, 1989) especially for snook. This study provides biological information and feeding habits on the species, which is abundant along the coast of South Australia, and to a lesser extent West Australia, Victoria and Tasmania. Catch and effort data is also analysed.

Figure 1: *Sphyraena novaehollandiae:* general view showing slender body and large mouth.

2. THE SPECIES

2.1. Distribution

S. novaehollandiae is a wide ranging species, occurring throughout the temperate regions and is distributed throughout the southern half of Australia, Kiribati, reputedly off Southern Africa (Smith, 1965), New Zealand (Last, et al, 1983), the South China Sea (Kwong-Chak Au, 1979), and the Maldives in the Indian Ocean (Blaber, pers com., 1993). See Figure 2.

Communication with Tasmanian, Victorian and West Australian State fisheries authorities indicated that minimal data was available, this due to the relatively small catches of the species in these States. (McDonald, MSL Vic; Lenanton, WA Dept of Fisheries; Williams, Tas Sea Fish.; pers. comm., 1994).

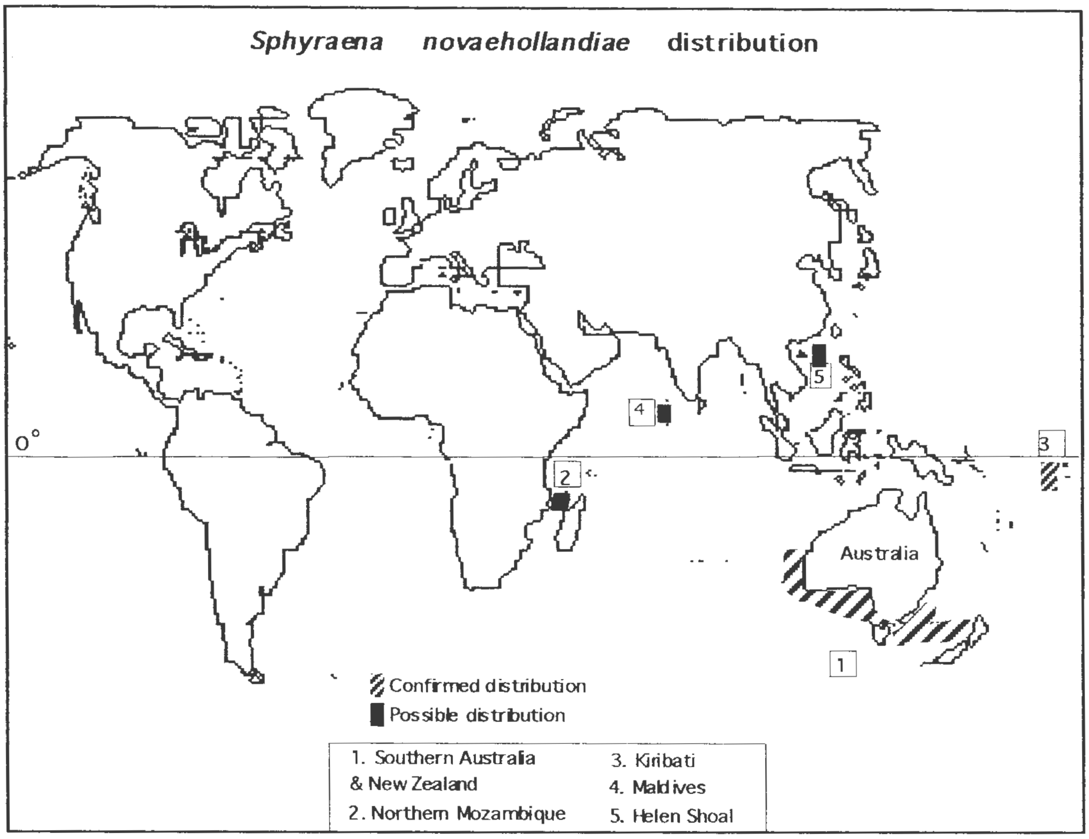


Figure 2: Areas of confirmed distribution and where possible capture of *S. novaehollandiae* has been recorded.

Due to the similarities, exact distribution is difficult to determine. Distribution is patchy, and it is seems anomalous that no snook catches has been recorded on the west and east coasts of northern Australia, although the species has distribution north of the equator.

2.2. Ecology

Anecdotal evidence indicates that snook like other sphyraena species, prefer shallow coastal seagrass (eg *Zostera* and

Heterozostera species) and kelp beds (*Phyllospora, Ecklonia, Cystophora* and *Sargassum* species). This is where their main prey is found, as well as seaweed waters on off-shore reefs rather than sandy, open habitats (Williams, 1959). The species is pelagic/semi-pelagic, highly migratory and occur in large shoals. Snook are commonly found in all the inshore waters of South Australia, but more prevalent in the two gulfs and the West Coast, with very few found in the South East (Bertoni, 1992).

Snook, like other of the Sphyraena genus, are voracious feeders, snapping willingly at moving objects in the water, (Scott et al, 1980). Their speed, up to 12 m/sec (de Sylva, 1973) make them formidable and efficient predators, feeding on small teleosts, cephalopods, crustaceans and bloodworms (*Glycera* species, Bertoni, 1993).

Exact distribution is unknown due to identification problems, and it is not known how tolerant the species is to low salinities or turbidity levels.

2.3. Seasonality and Movement

Snook are highly migratory and occur in large, fast moving shoals (Myers, 1989). Local fishers indicates that the species is distributed in depths of 20 metres and less (Bertoni, 1993). They are often encountered by divers in shallow waters of less than 5 metres suspended motionless in the seagrass beds, presumably waiting for prey.

3. TAXONOMY

3.1. Classification

Order Perciformes
Suborder Mugiloides
Family Sphyraenidae
One Genus - Sphyraena Rose, 1793
20 Species

The barracudas have traditionally been placed in a single genus *Sphyraena* Rose 1788. Fowler (1903), Whitley (1947), and Smith (1956), have suggested various genera for this family, but according to Schultz (1953), Williams (1959), de Sylva (1963), and Kwong Chak Au (1979, there is little evidence to disagree with other analyses of the family, namely that all species should be relegated to the genus *Sphyraena*.

Of the 20 species in the family only one *(S. novaehollandiae)*, is found in southern temperate waters, the other 19 species are commonly accepted as world-wide tropical or sub tropical species.

There is still some confusion regarding the taxonomy of the Sphyraenidae family and some species have not been adequately described. This is due to the similarities between:

1) the *S. jello, S. putnamiae* and *S. quenie* complex of species without gillrakers;

2) the *S. novaehollandiae, S. acutipinnis, S. helleri,* and *S. jello* complex of species with one gillraker and obliquely/rounded preoperculum;

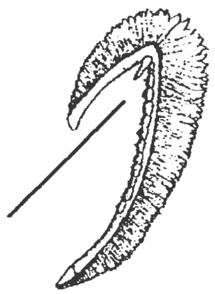
3) the *S. chrysotaenia, S. flavicauda,* and *S. pinguis* complex of species with two gillrakers.

3.2. Morphology

Distinguishing characteristics of the snook are:

1. 127-136 pored scales along the lateral line,
2. single gillraker (Figure 3),
3. slender, elongated body of 9-10 depth ratio to SL with protruding lower jaw,
4. rounded/obtuse preoperculum (Figure 4),
5. silvery/green colouring above lateral line, silvery below with silvery/greenish fins. A colour variation of dark brown to purplish brown is found off West Australia,
6. max length of between 91 and 103 cm,
7. max weight of 5.5 kg,
8. long narrow mouth with four pairs of large recurved canine teeth in the upper jaw followed by a row of

small teeth. The lower jaw has one pair of recurved teeth in front.



(Sources: De Sylva, 1973; Gommon, et al, 1994).

Figure 3: First gill arch in Sphyraena showing gill rakers of the snook and similar species, namely the *S. novaehollandiae, S. acutipinnis, S. helleri,* and *S. jello* complex.

(Source: Myers, 1989).

Figure 4: Preoperculum of Sphyraena showing obtuse and rounded shapes.

Table 1 describes the main morphological characteristics of the similar species in the *S. novaehollandiae, S. acutipinnis, S. helleri,* and *S. jello* complex with one gillraker and obliquely/rounded preoperculum.

Table 1: Similarities between species in the Sphyraena family.

Species	Membrane Flap	Preoperculum	Gillraker
S. acutipinnis	No	Obliquely rounded	single
S. helleri	Yes	Rounded	single
S. novaehollandiae	No	Obliquely rounded	single
S. jello	Yes	Rounded	single

(Sources: Lindberg & Legeza, 1965; Myers, 1989; Smith, 1986.)

The confusion of species is understandable due to the overlap of distinguishing characteristics, and possibly accounts for the patchy distribution of the snook.

Williams (1959) in his important study, stated that the barracudas of the world are much alike in morphology and general biology.

De Sylva, in another major study, noted the close similarity of *S. novaehollandiae* to *S. acutipinnis, S. africana* (now *S. acutipinnis),* and *S. helleri* - these are all slender barracudas with a single gill raker and first dorsal fin and pelvic fins almost in opposition. With the exception of the lateral line scale count, the other characteristics such as the shape of preoperculum, fin positions, etc may be shown to vary ontogenetically (de Sylva, 1973).

Other major studies done include a study on the barracudas of the South China Sea (Kwong-Chak Ua, 1979).

Further confusion exists with the *S. obtusata* species found off the New South Wales coast, which is similar to *S. acutipinnis,* and can therefore possibly be confused with *S. novaehollandiae,* and *S. helleri* (de Sylva, 1973). Smith and Heemstra, (1986), noted the similarity of *S. helleri* to *S. novaehollandiae.* The above indicates that a detailed osteological or electrophoretic examination of the genus may be required to better understand the status of members of this family.

4. THE FISHERY

4.1. Global

The barracudas are an important food source in the tropical and subtropical regions of the world. The species form an important part of the catch in India, Indonesia, Thailand, the Philippines, and the western United States. The species are also an important food source in the island nations of the Pacific region, with catches being part of inshore and lagoon subsistence fisheries. Global landed catch was 64,195 tonnes in 1991 (FAO, pers comm, 1993). Catches are mainly taken by trolling. By contrast, little commercial importance is placed on snook catches in temperate waters.

4.2. In Australia

4.2.1. Commercial fishery

When compared to other industrialised countries or the other States of Australia, the South Australian snook fishery is very small, but unique in that most fishing occurs within a few nautical miles of the coast (as with the other marine scalefish species). As an inshore fishery, small, owner operated vessels (av length 5.5 metres), with a crew of one to two persons, are able to target the inshore species in shallow water of less than 5 metres, at relatively low fishing costs (Figure 5). Day trips are made to the fishing grounds, which are only two to three nautical miles from the coast, and most weekends are spent in port. The fishing method is largely with haul nets, with a small percentage of operators using trolling. A small number of fishers use larger vessels of 10-11 metres, called "mother ships", with 2/3 crew, from which two or three smaller vessels (5 metres length) operate using haul nets. These "mother ships" usually stay out on the fishing grounds for 2-3 days.

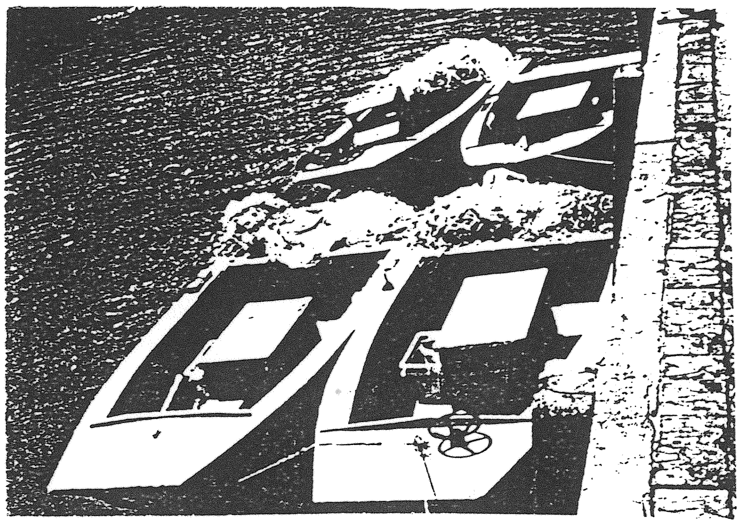


Figure 5: Haul nets vessels at Port Wakefield, South Australia.

The fishery is highly weather dependent due to the small size of the vessels, most fishers are unable to venture out to the fishing grounds when the winds are over 15 knots.

It should be noted that when targeting other species, such as southern sea garfish *(Hyporhamphus melanochir)* undersized and immature snook are caught by the haul netters due to the small mesh sizes (3 cm minimum).

Most of the catch is boxed and iced and sent on a daily basis to wholesale buyers for sale to retail outlets by the individual fishers (Jones, 1993). Some fish are sent on consignment to wholesale markets, where fish are auctioned to registered buyers on a commission basis. All of the landed fish are consumed locally.

4.2.2. Recreational Fishery

Snook are a popular target species for recreational anglers. In a recreational study in 1990 (Jones and Retallick, 1990), snook was the 5th most taken species with King George whiting *(Sillaginodes punctata)* and tommy ruff *(Arripis georgianus)* the most popular. In a metropolitan boatfishing survey in 1990-91 (McGlennon, 1992), snook was the 12th most landed species. The species is caught by trolling and occasionally by hand lines.

There is no information on total landed catch, but from personal observation, the snook is popular with recreational fishers (Bertoni, 1993, 1994).

4.3. Management Controls

In South Australia commercial fishers are restricted to using power haul nets to depths of less than 5 m of water; in fact the net footrope usually scrapes the sea bed.

Other regulations for commercial fishers are limited entry (since 1977), with a freeze on the transfer of licences being in force since 1982 (except in the case of a family transfer), and gear restrictions. At present there are 157 licence holders, although not all licensed fishers are active in the fishery. Licensed fishers are required to forward to the Fisheries Department daily catch and effort information in log books.

A minimum legal size of 36 cm. applies to both commercial and recreational fishers. Up to 30 August 1994 there was no bag limits for either the commercial or recreational fisheries. From 1 September 1994, new legislation in South Australia introduced a bag limit of 25 for shore recreational fishers and 75 for boat recreational fishers. Commercial fishers are unaffected.

4.4. The Study Areas

The study area is situated between 38° S to 32° S, and 132° E to 140° E at the southern fringe of the Australian continent. The temperate waters of South Australia consists of a variety of habitats, namely estuaries, shallow bays, mudflats and mangroves, shallow grassbed zones and rocky exposed headlands (Figure 6).

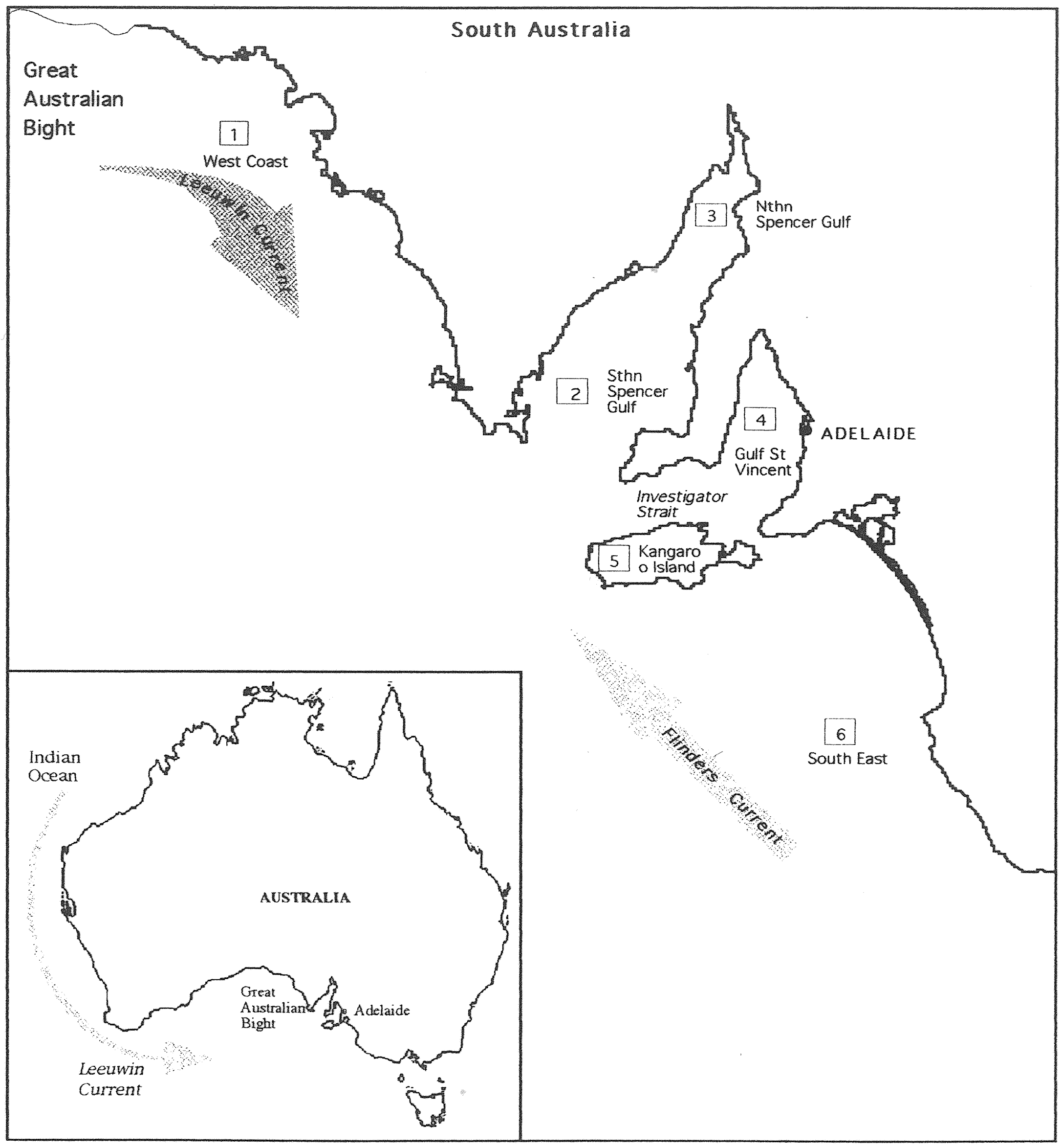


Figure 6: Major oceanic current influences in South Australian waters.

The two gulfs are relatively shallow marine basins, providing protected waters, and Kangaroo Island to the south acts as a buffer that provides some protection for both gulfs. Seagrasses cover large areas of South Australian bays and gulfs from intertidal to 20 metres water depth. The common sea grasses *Amphilibolis*, *Zostera* and *Heterozostera* ('eelgrasses' mainly inhabiting low inter-tidal mudflats) are found in both gulfs. (King and Shepherd, 1982). These grasses are important in several ways. They assist in stabilising the sediments; the sea-grass beds baffle wave action and reduce water movement. These seagrassed gulfs and sheltered bays are also important nursery areas for many species of marine organisms and teleost species.

Algal communities are prominent on rocky bottoms on the subtidal cliffs and rocky shores bordering lower Gulf St Vincent (Shepherd and Sprigg, 1976).

The South East has low dunes and wide sandy beaches, and is more wind-swept with predominantly south-easterly winds that drive the surface waters offshore. The cool Flinders Current has summer upwellings at the continental shelf that bring nutrient-rich waters to the surface

5. PREVIOUS WORK DONE

5.1. Biology

No previous research had been undertaken on the biology of the snook.

5.2. Growth Data

Bertoni (1992, Appendix A) analysed unsexed length frequency data using ELEFAN I (Pauly, 1981), and obtained estimates of the parameters of the von Bertallanfy growth curve, L_∞: 94.4 cm and K: 0.256 year $^{-1}$.

5.3. Length Weight Relationships

The relationship of length to weight was fitted by an exponential curve to the form $W=aL^b$, where W = Weight (g) and L = Total length (cm). This resulted in the form $W = 0.0035\, L^{3.05}$.

6. RESEARCH AIMS

The present regulations for management of the commercial snook fishery are a minimum size limit of 36 cm and licence freeze since 1977 in the multi species commercial Marine Scalefish fishery in South Australia.

It is unknown whether the size limit is biologically meaningful, as there are no data on size at first sexual maturity, no validated age/growth information, and no reproductive information. There is a need to determine whether snook are major predators of other commercially and recreationally important species, such as King George whiting *(Sillaginodes punctata)* and southern sea garfish *(Hyporhamphus melanochir,* Jones per. comm. 1993).

The objectives of the current research are:

1. To investigate the reproductive biology of snook with special reference to:

    a) sex ratio of catches,
    b) age/size at first maturity,
    c) fecundity,
    d) determination of spawning season
    e) whether serial or batch spawners

2) The validation of previous growth estimates through the use of fresh data and otoliths, as a preliminary inspection of scales indicate difficulty in reading the annual rings. In addition, determination of growth of the separate sexes.

3) To study the position of snook in the inshore food chain, through the analysis of stomach contents.

4. Total mortality estimates of the commercial catch data.

7. MATERIALS AND METHODS

7.1. Data Collection Regions

For convenience of data collection and analysis, the fishing areas were divided into seven fishing regions. These regions follow the South Australian Marine Fishing Areas, which records commercial catch and effort logbook returns of licensed commercial fishers using coded blocks of approximately 60 x 60 nautical miles (Figure 7). The sample sites where specimens were collected is shown, and samples from these sites were used for all subsequent analysis.

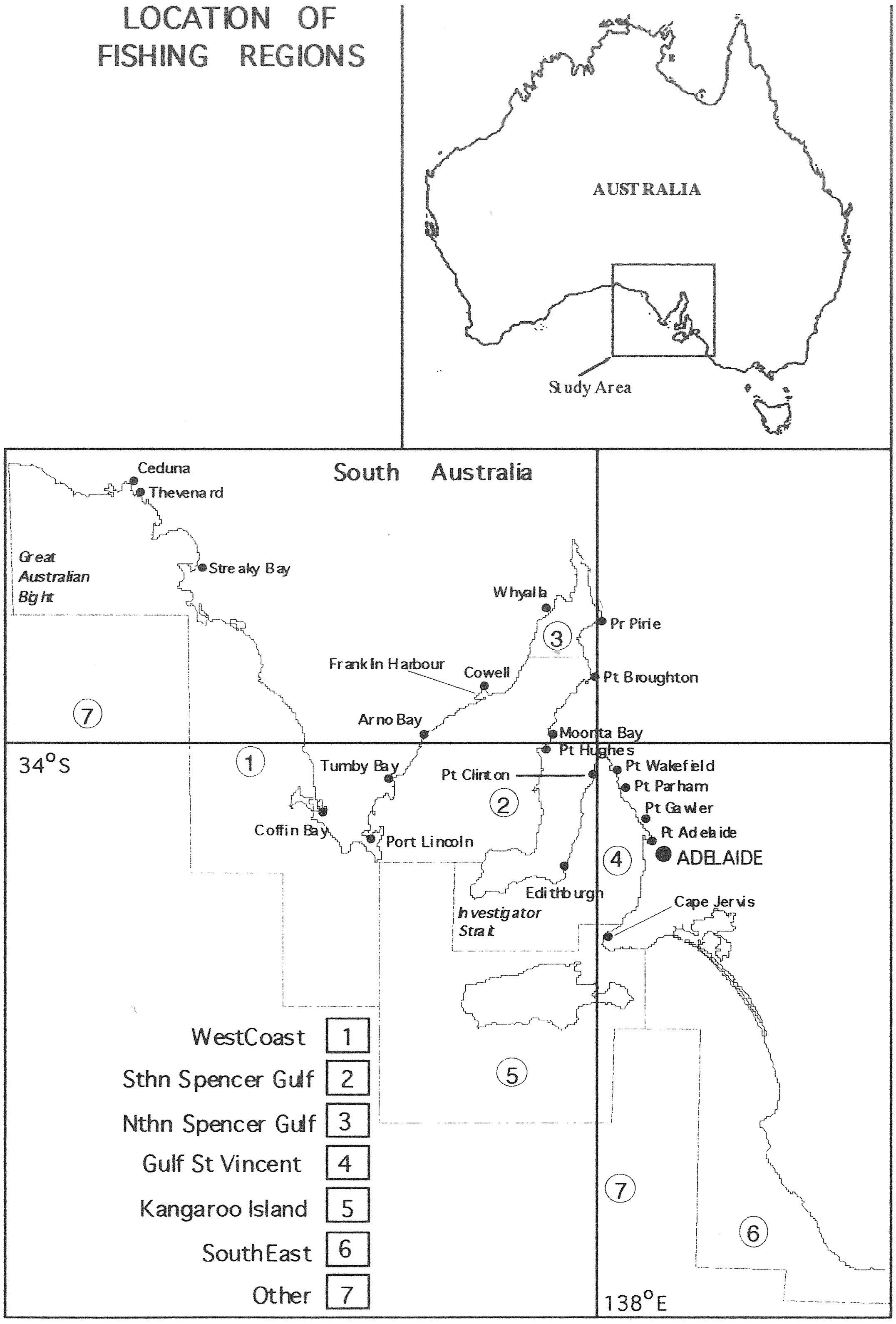


Figure 7: South Australian fishing ports where specimens were sampled, and the seven statistical regions.

7.2. Types and Methods of Data Collection

The period of study was undertaken over a 12 month period from early May 1993 to the end of May 1994, with a total of 955 specimens collected and examined. Data sheets and length frequency sheets were used to record all information, and each sample batch was recorded by catch method and area fished. Sequentially numbered plastic bags were used to label each specimen collected. All data were entered into an Excel spreadsheet, and sketches and line drawings were computer generated using "Canvas", a drawing/paint application, and graphs were generated in "Deltagraph Professional". Statistical analysis was carried out using "Statistica" analysis software. Photographs were either scanned and placed into the final draft or laser copied. A Sartorius electronic balance accurate to 0.01 g was used for all weights, and otoliths and gonads were viewed under an optical stereo microscope.

7.3. Fish Sampling

Sampling of commercial catches from the 7 fishing regions was undertaken on a fortnightly basis. A sample batch consisted of a minimum of 20 specimens. From the beginning of November 1993, as spawning approached, a larger number of specimens (up to 40) was collected for each sample. Most of the specimens were randomly collected at a major fish wholesaler/processor near Port Adelaide, where fish were purchased directly from various licensed commercial fishers as well as from the wholesale auction market. This gave a good spread of fishing regions. Approximately 10% of the sampling was obtained from the individual fishers operating from Port Adelaide, North Haven (just south of Port Adelaide), Cape Jervis, Ceduna, Whyalla, and Port Lincoln.

7.4. Reproduction

Gonads were removed from all fish obtained from sample sites to determine maturation, and all specimens collected for analysis were staged and recorded on the data sheets.

7.4.1. Gonad Staging

Six maturity stages for females and four for males were recorded with stage V describing the females fish ready to spawn (Table 2). Premalatha and Manojkumar (1990) used these stages to describe the gonad maturity states for two other Sphyraena species *(S. jello and S. obtusata).*

Table 2: Development of the gonads for males and females.

Males

Stage		
I	IMMATURE, MATURE RESTING	Testes small, threadlike, no sperm
II	MATURE RIPENING	Testes moderate, sperm extruded on cutting and squeezing
III	MATURE RIPE	Testes enlarged, lobate, sperm extruded on cutting or with pressure on flanks
IV	MATURE SPENT	Testes crinkled and shrunken, little sperm, some residual blood clots

Females

Stage		
I	IMMATURE	Ovaries very small, threadlike, pink/opaque
II	MATURE RESTING (OR VIRGIN)	Ovaries small to moderate, eggs microscopic, pink to orange/opaque
III	MATURE RIPENING	Ovaries moderate, eggs visible to naked eye, opaque
IV	MATURE NEARLY RIPE	Ovaries enlarged and distended, eggs clearly visible, opaque, some translucent
V	MATURE RIPE & RUNNING	Ovaries enlarged, distended tunica bursts easily, nearly all eggs transparent
VI	MATURE SPENT	Ovaries flaccid and shrunken, some residual eggs, many residual blood clots.

7.4.2. Gonad Weights

Whole fresh weights of both the gonads were recorded to the nearest 0.01 g.

7.4.3. Sexing

Sexing of each specimen was carried out where possible and recorded. Specimens were not sexed where development of the gonads at the macro level was not discernible.

7.4.4. Sex Ratio of Catches

The monthly sex ratio of all sexed specimens was recorded.

7.4.5. Oöcyte Counts and Fecundity

A sub-sample of 5-6 ovaries from each batch were examined immediately after removal. These oöcytes were chilled but not frozen to ensure that no changes in oöcyte size occurred.

Sub samples of 2 grams from the anterior, middle and posterior regions of both ovaries were taken. The sub samples were immersed in warm water to separate the oöcytes from the surrounding tissue, and counted in 90 mm petri dishes marked with 1 cm square grids against a black background -

this facilitated the egg count process. A stereo microscope at a magnification of 10X was used to determine counts.

Fecundity (F) was determined by the following formula:

$$F = (\sum N \text{ in all size classes} * \text{gonad wts})/2$$

This gave the absolute fecundity of each pair of ovaries examined.

7.4.6. Oöcyte Diameters

The oöcytes were counted according to their approximate diameters. Preliminary examination of the ovaries indicated 4 classes of oöcytes. The frequency in the largest oöcyte class was used to determine when the maximum oöcyte diameter (MOD) occurred. The timing and approximate duration of the spawning season was investigated by monitoring monthly changes in maximum oöcyte diameter.

7.5. Gonadosomatic Index (GSI)

The gonad weight as a percentage of total body weight was determined for all the samples on a monthly basis. Total body weight was measured to the nearest 5 grams and gonad weight to the nearest 0.01 gram.

The following formula was used to determine the GSI:

$$GSI = \text{Gonad Wt}/(\text{Body wt} * 100).$$

7.6. Condition index

The condition index was used to compare the relative condition of the fish.

The constant of the length-weight relationship ($W = aL^b$) was used as a condition index:

$$C = W/aL^b$$

where W = weight in grams and L = total length in cm.

The above condition index formula is most commonly used in South Australia by the South Australian Research and Development Institute (Aquatic Sciences), and is useful in investigating seasonal weight changes in relation to food availability and reproductive cycles, and can be used to indicate the best period for harvesting (Bolger and Connolly, 1989).

The condition indices for males and females were analysed separately on a monthly basis.

7.7. Stomach Contents

Stomach contents were examined from each specimen collected, and where possible, (ie digested state allowed identification), species of prey identified and recorded. This was summarised and analysed on a monthly basis.

For recording purposes teleosts found in the stomach were categorised into the following length classes:

< 2.5 cm:	small
> 2.5 - 5 cm:	medium
> 5 - 7.5 cm:	large
> 7.5 cm:	very large

These were entered into the spreadsheet under the stomach contents column in this format. Crustaceans and cephalopods were measured and recorded in mm.

7.8. Lengths

Previous length frequency data of snook collected by the Department of Fisheries used total length measurements, and all specimens collected for this study used this procedure, recorded to the nearest one cm below.

7.9. Weights

Total weights of each specimen were recorded to the nearest 5 grams.

7.10. Sagittal Otoliths

These were collected from each specimen, cleaned in warm water, dried, and weighed to the nearest 0.01 g. Care had to be taken when removing the otoliths, due to the shape and the narrowness of the head. Approximately 1% of the otoliths were not used due to breakage. The otoliths were stored in 2ml Auto Analyser cups.

Two methods of viewing the otoliths were used:

1. A selection of whole otoliths from fish ranging from 24 cm to 88 cm were viewed under microscope to determine growth zones. The otoliths were immersed in water, and viewed against a black background usually at 40X, using reflected light illuminated from above, and this gave the opaque zones a light appearance, and the translucent zones a grey appearance.

2. Otoliths were set into clear resin blocks in groups of 8 per block (2 rows of 4 otoliths), and two transverse sections were taken across the nucleus using a gem faceting machine (A-A, Figure 8a). These sections were

0.5 mm thick and polished smooth using a fine 2000 grit wet and dry paper, and glued to microscope slides. Examination was under a stereo microscope using transmitted light at 40-50X magnification. Immersion oil (pure aniseed oil) was used to enable easier identification of the growth zones. The growth increments were read by the researcher without identification as to sex or size, counted and the age classes determined. Increments were counted along both the L1 and L2 axes. A random batch of 100 otoliths were read by an experienced ageing scientist at SARDI to verify the growth increments. The distance from the last complete translucent increment to the edge (the marginal increment) of each otolith was measured along the L2 axis as indicated in Figure 8b. If increments are formed at approximately the same time each year, then these measurements would differ for the various times of the year. All measurements are in μm.

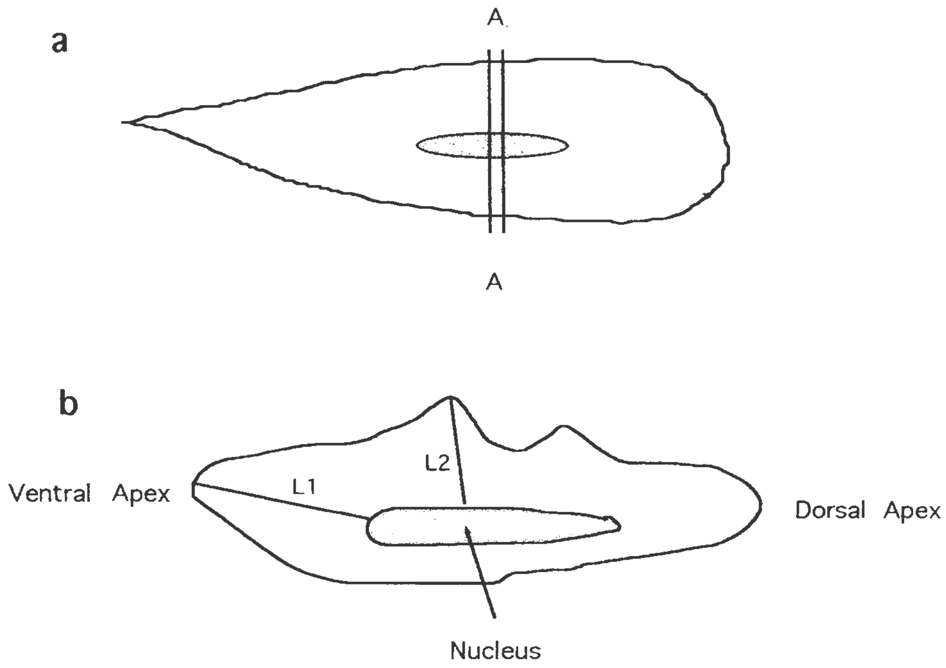


Figure 8: Snook otolith. a: whole otolith, with A-A lines indicating the two transverse sections. b: sectioned otolith, indicating where increments were counted (L1, L2) and marginal increment measured (L2).

In both methods the opaque zones are identified and counted (FAO 1981).

The opaque zone is formed during the period of greatest growth (usually summer), and is usually wider than the translucent zone which is laid down during the period of slowest growth (usually winter). In temperate waters the main zones may be caused by summer - winter variations in the environment (FAO Fish. Circ No. 736, 1981).

Estimation of ages for males and females were interpreted separately using FISHPARM, a fisheries software application which fits the von Bertalanffy growth curves to estimate the size-at-age and gives the L_∞, K and t_0 estimates.

7.11. Total Mortality

Instantaneous total mortality (Z) for all fish as well as males and females separately, was estimated using length-converted catch curves. The length frequency distributions were converted to relative age frequency using the growth parameters of K and L_∞. The values of $Ln(N/\Delta t)$ were plotted against t and takes into account the time for a species to grow through a length class (Δt), and allows for the fact that growth slows with increasing size (Pauly, 1983). The relative age t, which is the mid point of each length class, L_t, is calculated using:

$$t = (-1/K)\ Ln\ [1-(L_t/L_\infty)]$$

The initial ascending data points were not used and represent fish which are not fully recruited or are too small to be totally vulnerable to the gear. The slope of a regression line indicates the total mortality rate.

7.12. Field Trips to Country Areas and Interstate

Field trips to gather specimens and fishing information was made to Port Parham, Port Wakefield, Port Augusta, Whyalla, Port Lincoln, Coffin Bay, and Cape Jervis. At theses centres, fishers were also accompanied on their vessels to observe fishing methods. One field trip was made to Victoria and to Western Australia to gather data and information, and to have discussion with that State fisheries authority.

7.13. Vessel Trips

Trips were made on 5 haul net vessels and on 1 trolling vessel in the country areas, and 1 haul net and 2 trolling vessels in the metropolitan area to observe fishing methods and practices. Two trips were made on recreational vessels.

7.14. Method of analysing data sets

Where appropriate, data was tested for significance using analysis of variance and t-tests, and 95% confidence limits used.

The Pearson correlation matrix was used to test the linear fit (r^2) of data.

For hypothesis testing, a .05 criterion of significance was used.

7.15. Growth

Length frequency data was used to determine the L_∞ and K values in the von Bertalanffy growth equation (von Bertalanffy, 1938) using ELEFAN I (Pauly, 1981). For ELEFAN I, the length frequency samples were pooled into 2 cm size classes. The 12 monthly samples was run as one file. ELEFAN was run as many times as necessary until a satisfactory fit, ie best Rn value, of the data was achieved. The program attempts to pass the growth curve through as many of the length modes as possible, and this generates a Rn value as an indication of the goodness of fit; a perfect fit being a value of one. Analysis was done on males and females as well as combined data.

A modified Wetherall Plot (Wetherall, 1986), was used to validate L_∞ and was used to give an indication of age/length at first capture.

Length frequency histograms were graphed, and the growth parameters, L_∞ and K were used in a von Bertalanffy plot to suggest an approximate maximum age.

The von Bertalanffy function is usually written:

$$L_t = L_\infty(1-\exp(-K(t-t_0)))$$

Where: L_t is length at age t

L_∞ is asymptotic length

K is a parameter describing how rapidly L_∞ is achieved

t_o is the hypothetical age at length zero

Lengths were to the nearest cm and weights to the nearest 5 gram.

7.16. Length/Weight Relationships

The relationship of length and weight for males and females was fitted by an exponential curve of the form:

$$W=aL^b$$

where W = weight in grams, L = total length in cm, *a* is a constant and *b* is an exponent relating weight to length.

The length weight relationships for juveniles were determined separately.

All measurements were rounded down as is the accepted convention in studies of fish stock assessment (Anderson and Gutreuter, 1983).

8. RESULTS

8.1. The Fishery

8.1.1. Catch Methods and CPUE

Due to higher efficiency, hauling nets have displaced trolling as the preferred fishing method for commercial fishers in South Australia. Figure 9 gives the percentage proportion of haul net to trolling catch for each fishing region and clearly indicates the preference of haul nets in most areas.

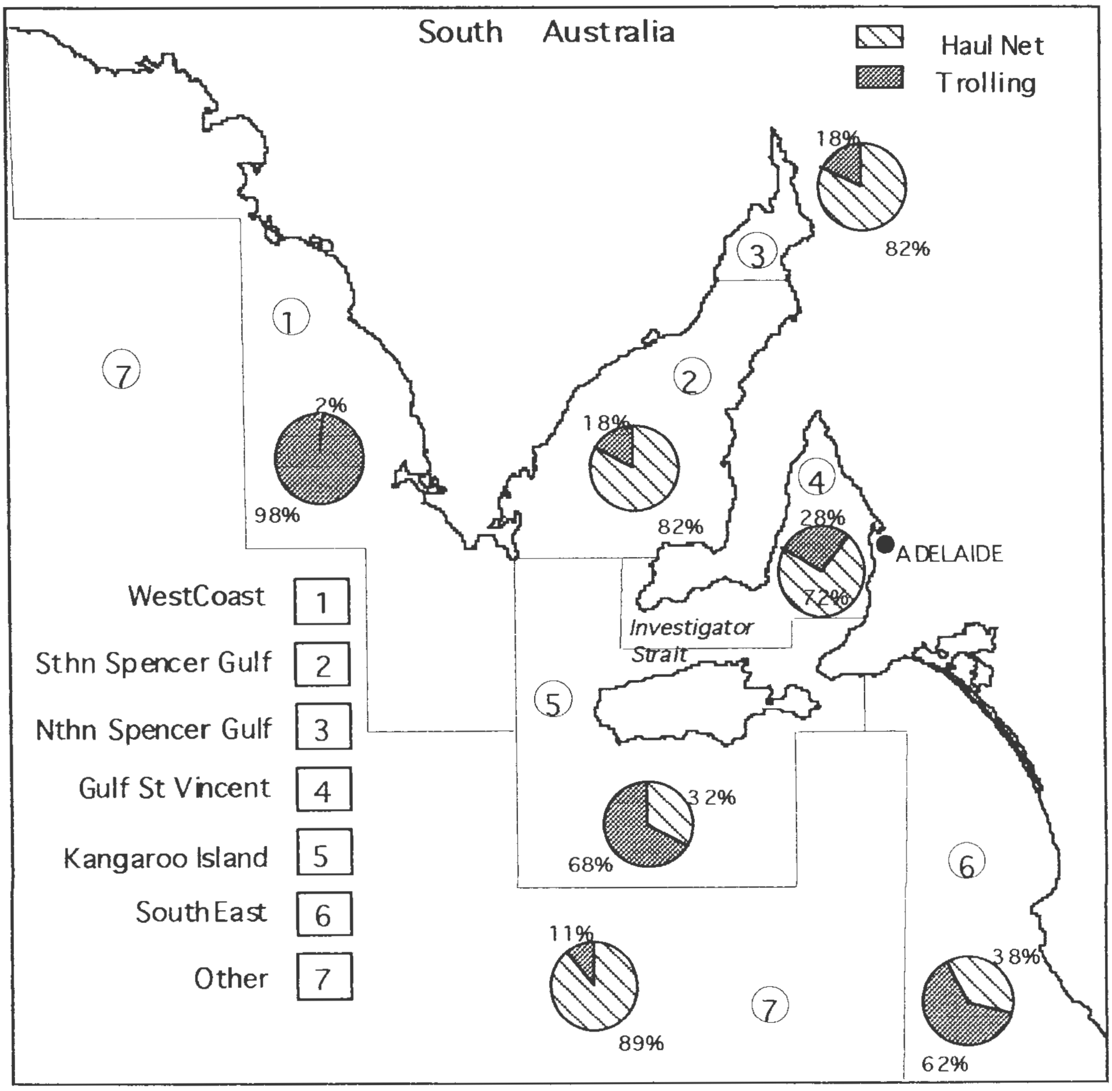


Figure 9: Snook haul net and troll catches for each fishing region, expressed as a percentage of total.

Hauling net effort have increased by 50% and catches by 240% in all areas of South Australian waters from between 1976/77 and 1991/92 (Figure 10).

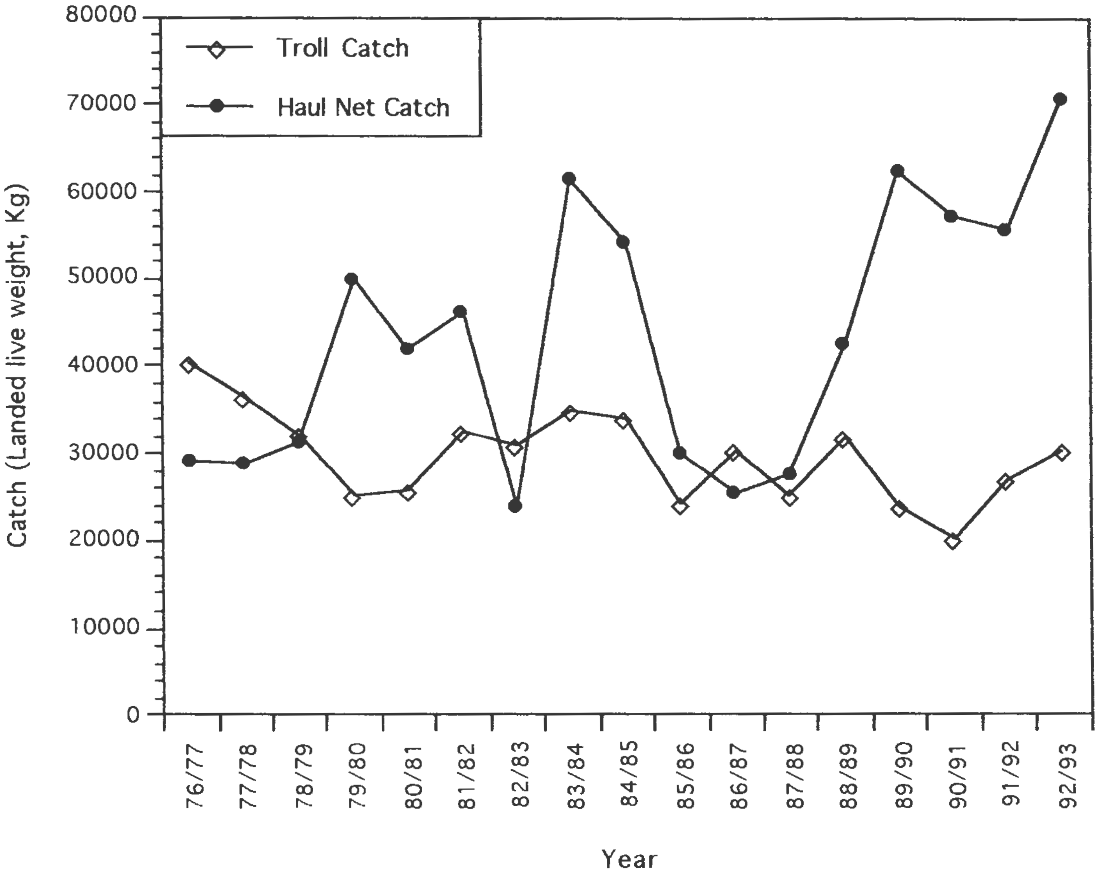


Figure 10: Snook haul net and troll catches (landed live weight) to 1992/93.

Trolling effort and catches have decreased 56% and 41% respectively in all areas in the same period, although the in last year of available data (1992/93), a big increase in catches occurred with effort back to 1976/77 levels. CPUE for haul nets has increased, while CPUE for trolling has shown a decline up to 1992/92 (Figure 11).

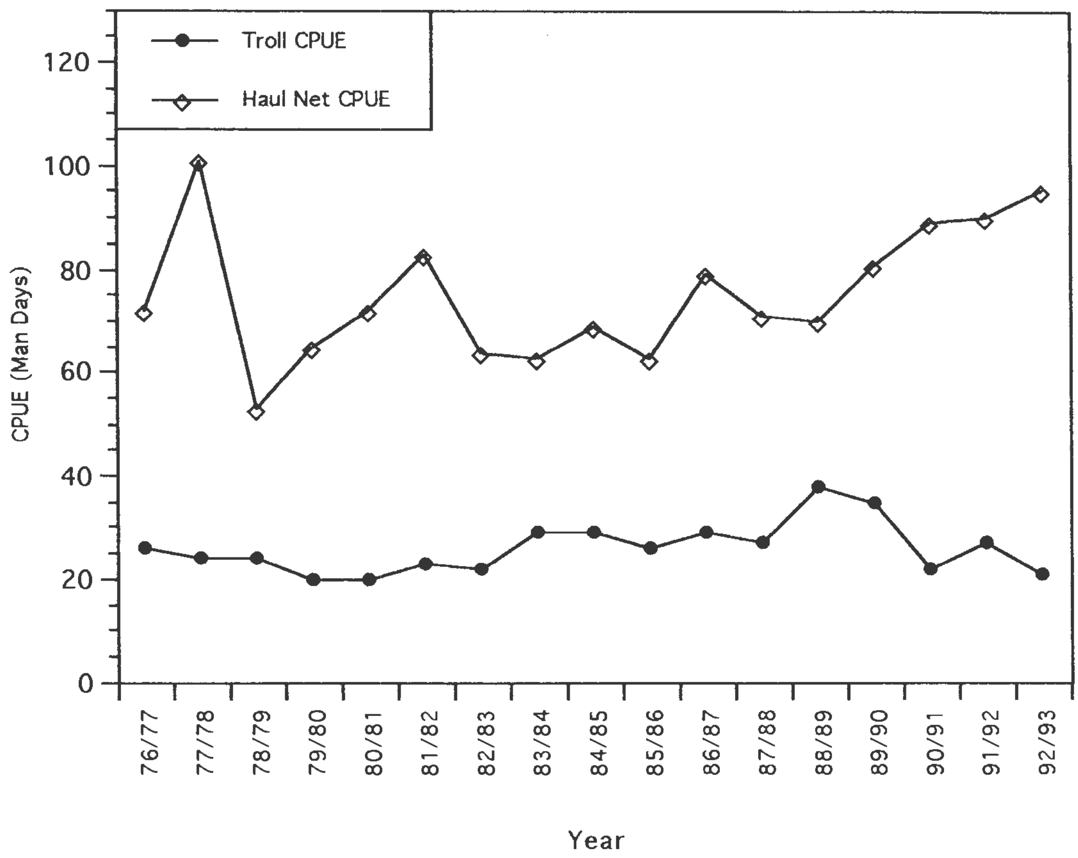


Figure 11: Snook CPUE (Boat-days) of haul net and troll to 1992/93.

Catch and effort results in South Australia (Bertoni, 1992), shows large seasonal fluctuations, with most hauling net effort and catches occurring in autumn and winter (April-August). Snook is generally caught as a by-catch, due to hauling net effort targeting the more highly valued, important shallow waters species such as King George whiting *(Sillaginodes punctata),* yellowfin whiting *(Sillago schomburgkii)* and southern sea garfish *(Hyporhamphus melanochir).*

Trolling effort and catches for snook occurs over summer to early autumn (November-April). During late autumn and early spring (April-May, September-November) the troll fishers target southern calamary *(Sepioteuthis australis),* King George whiting and occasionally southern sea garfish.

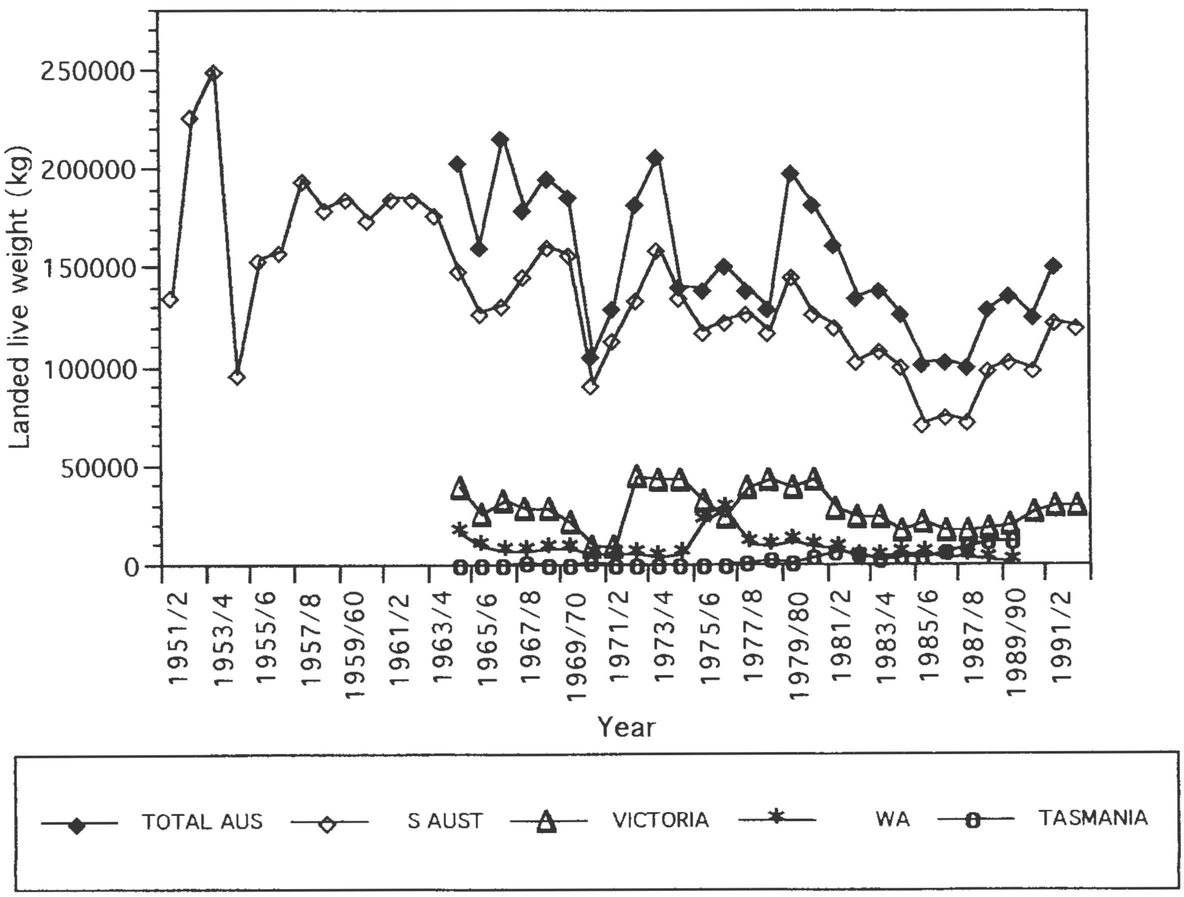
8.1.2. Catch and $ value

Landed catches and values for snook in the commercial fishery of South Australia for the past 3 years were: 1990/91 - 99 tonne ($220000), 1991/92 - 123 tonne ($218000), 1992/93 - 121 tonne ($263000) source: SARDI, Aquatic Sciences, 1993. No dollar value on commercial snook catches are available from West Australia, Victoria, and Tasmania (personal communication, 1994) due to the small size of the fishery in these States. Fishers received a peak price of $5.00/kg whole weight at the wholesale markets in South Australia (summer 1993-94) for snook, with an average price of approximately $2.20/kg. This compares with a peak wholesale price of $13-13.50/kg for King George whiting and $9.00/kg for garfish over the same period (SAFCOL, personal communication, 1994). This indicates that the snook is still relatively underpriced in relation to other popular table fish.

In 1992/93 153 tonnes were landed by the commercial sector in Australia. The available catch details for the States is given below. No catch weight data are available for Tasmania or Western Australia

State	*Tonnes*
South Australia:	121
Victoria:	29
Tasmania:	NA
Western Australia:	NA
Total Australia:	154

Figure 12 gives the commercial landed live weight for the snook for each State, and the total for Australia, up to 1992/93. The South Australian catch comprises 90% of the total Australian landings.



Note: Total landed weights for Victoria includes long-finned seapike and unidentified seapike.

Figure 12: Total commercial landings of snook for each State and Australia overall.

Figure 13 indicates the landed live weight of snook for the commercial sector in South Australia from 1951/52 to 1992/93. Although the trend is generally downwards after peaking in 1953/54, the last four seasons have shown a significant increase in landed catches.

Figure 13: Total snook landings for South Australia from 1951/52 to 1992/93.

8.2. Gonads

8.2.1. Gonad Maturity

A description of the different stages of the ovaries are as follows:

1. Chromatin nucleolar stage,
2. Perinucleolar stage: Stages 1 and 2 are usually referred to as the primary growth phase,
3. Yolk vesicle (cortical alveoli) formation: characterised by the appearance of yolk vesicles in the cytoplasm,
4. Vittelogenic stage: the appearance of yolk proteins in fluid-filled spheres,
5. Mature (ripe) stage. The release of oöcytes into the ovarian lumen.

Visible signs of gonad development were noticed from August 1993 for males, and from September 1993 for females. Separate sexes could be identified from mid July. Prior to this, (from May to mid July) the gonads were very small and the sexes could not be determined with confidence without histological methods.

The monthly maturity states for males and females are shown in Table 3. Monthly gonad development in both sexes could be seen as the ovaries and testes matured.

Table 3: Monthly maturity progression of snook gonads, May 1993 - April 1994.

Month	Occurrence of pre-adults	Males I	Males II	Males III	Males IV	Females I	Females II	Females III	Females IV	Females V	Females VI	Ttl M	Ttl F
July	2	13				22	3					13	25
Aug	0	7	6			1	24					13	25
Sept	1	1	16				1	15	2			17	18
Oct	2		2	3	1			13	17			6	30
Nov	3	2	42					4	24	9		44	37
Dec	2	1	1	4		5			14	33		6	52
Jan	1	2	8	11	5		2	1	3	10	6	26	22
Feb	27*	9		1	9	4				3	18	19	25
Mar	33*	4			8	6				3	15	12	24
April	13*	1			8	6				1	17	9	24

* Large number of pre-adults due to sampling at Port Lincoln, Whyalla, Port Wakefield and Port Clinton.

The spawning season for the snook is quite short and took place from late November 1993 to the end of January/early February 1994, after which a significant decline in numbers of ripe and running fish indicates an end to spawning activity. Ripe females were sampled from late November, and after 10 February 1994, almost all specimens had spent gonads, with only 7 specimens found with ripe gonads, from a sample of 282 females.

8.2.2. Gonosomatic Index (GSI)

Gonad indices reach a high of 6.6% for females and 6.4% for males in December (Figure 14). The GSI for both sexes drops off rapidly after this, confirming the trend in gonad maturation that the species spawns from late November to January/early February.

As both males and females peak at the same time, this indicates that both sexes can be used to determine time of spawning.

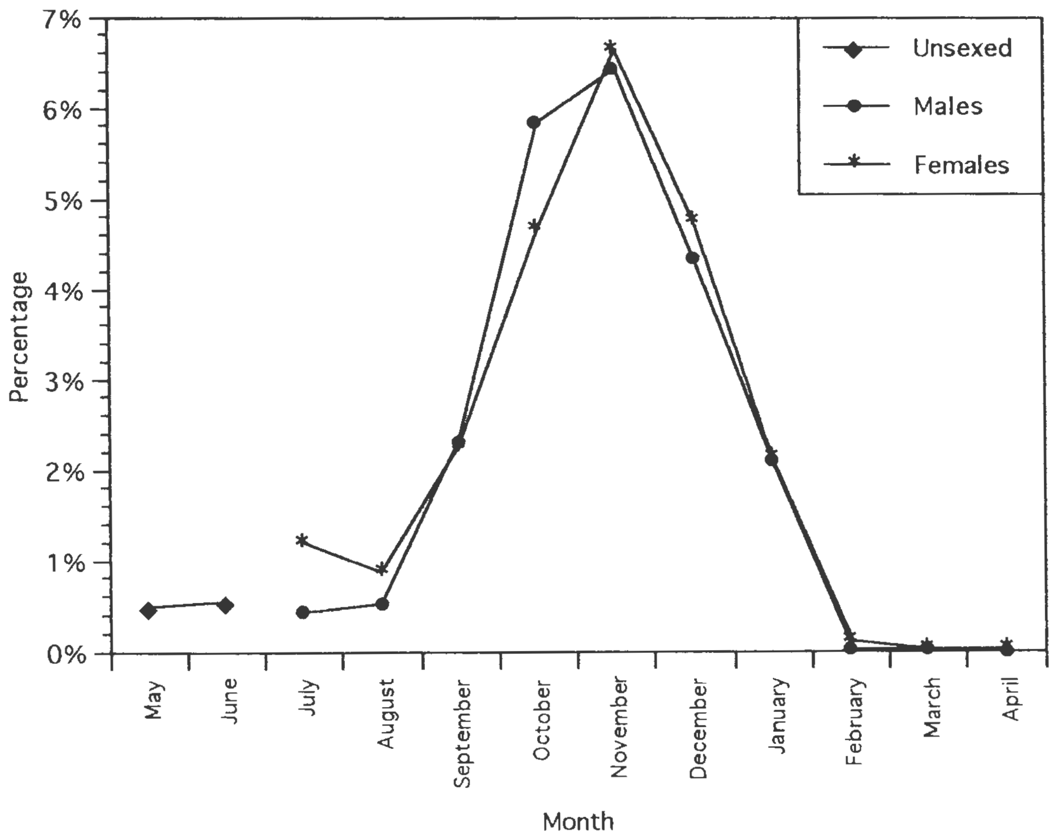


Figure 14: Gonosomatic Index for the snook.

8.2.3. Condition Indices

The species had a low condition factor from April which rose slowly during the winter as they fed. Mesenteric fat was often deposited along the gonads from July onwards as the fish built up condition prior to spawning. Condition reached a maximum in November, and this, with GSI and oöcyte diameters, indicate that spawning would occur soon. Spawning took place nearly a month after this date, from late November to January/early February (Figure 15).

Condition declined rapidly from December to January while the species spawned, and then levelled out from February. It was noticed that the condition indices of the males was slightly higher than females, with greater variability between months. However females were in better condition after spawning.

Values greater than one indicate a heavier than average fish, and less than one, lighter than average fish.

From the indices, it is apparent that the best time for harvesting is from October to December, when the fish are at their highest weight (from a price point of view) and the lowest weight was just before and after spawning (August - September and February).

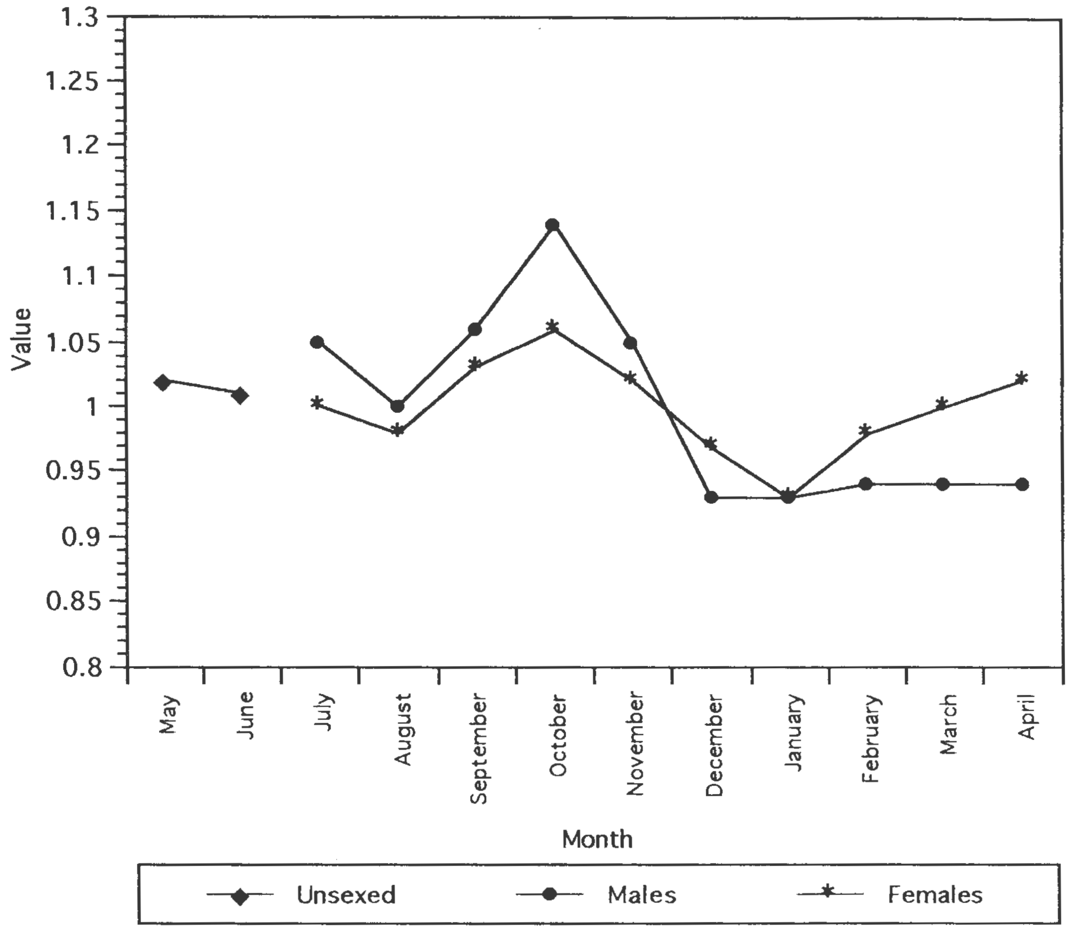


Figure 15: Condition Indices for the snook. Dotted line is the mean.

8.2.4. Spawning and Spawning Season

During the spawning season, almost all the females over 41-42 cm total length were in reproductive states. There were only 7 non-reproductive females over 42 cm total length; less than 2.5% (282 female specimens).

From the gonad and spawning data gathered, the species is probably a serial batch spawner, and spawned between late November and January/early February, when stage V for the females was reached.

During January and early February there was a distinct absence of fish on the fishing grounds, with very few fish being available. Personal communication with fishers in both the gulfs confirmed this, and suggests that the snook probably move offshore to spawn. The flaccid and bloody appearance of the spent ovaries made identification of the spawned fish relatively easy.

From these results, and with ovarian development studied over the 12 month period, it is clear that the species spawns only once a year.

8.2.5. Oöcyte Counts and Fecundity

The eggs were transparent at the last two stages (IV and V) prior to spawning ("tapioca") with the yolks clearly visible in stage V (vitellogenic stage). Fecundity increases as the females grow, from an average of 40,000 eggs at maturity (42 cm total length) to just under 500,000 eggs at 67 to 75 cm.

The fecundity counts were taken to the end of February (ie to the end of the spawning period); gonads examined for oöcytes counts from March were not included in the fecundity analysis.

Fecundity increased with length from 42 cm up to 75 cm, total length. Above 75 cm, there was a marginal drop in fecundity, but no conclusion could be drawn on this, as only a single specimen above 75 cm total length was collected. It can be concluded that fecundity increased from 2.4 years (42 cm) to 6.1 years of age (75 cm), and average fecundity was 375000 oöcytes per fish. The presence of oöcytes of all sizes suggests that spawning may have occurred over a period of time.

There was a significant relationship between absolute fecundity and length and weight for the species. A linear equation gave the best fit for fecundity/length relationship, and a power curve gave the best fit for the fecundity/weight relationship.

Figures 16 and 17 shows the relationships between fecundity/length, and fecundity/weight.

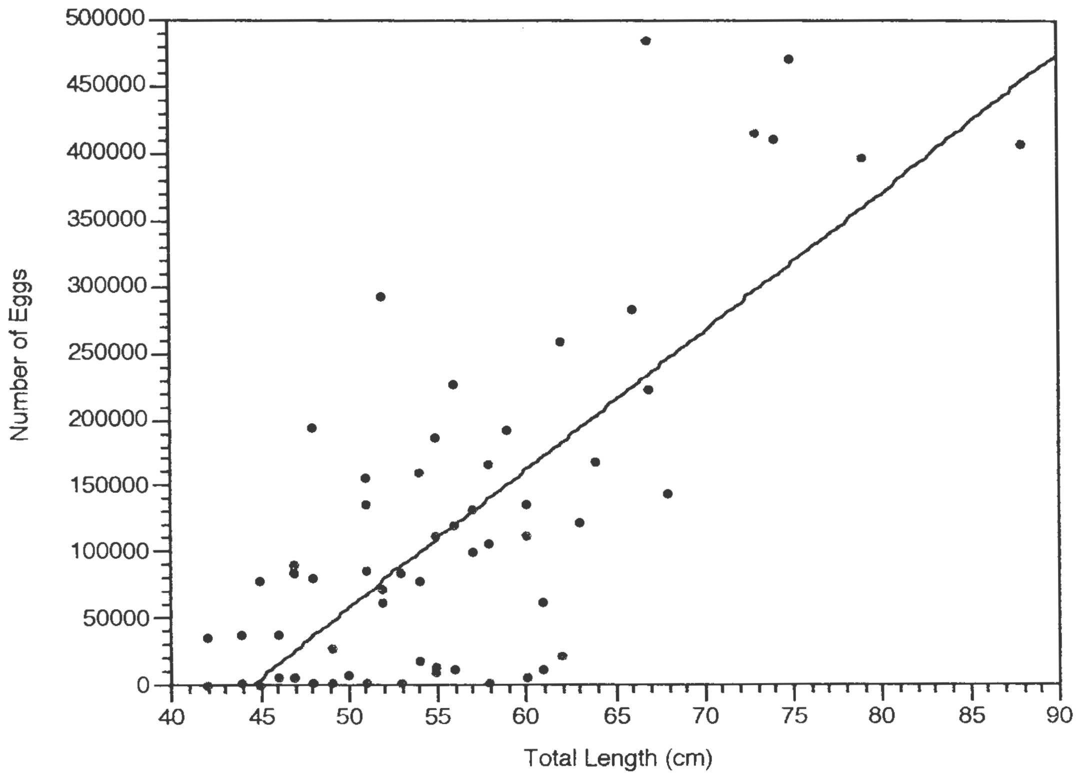


Figure 16: Snook fecundity to fish length relationship.

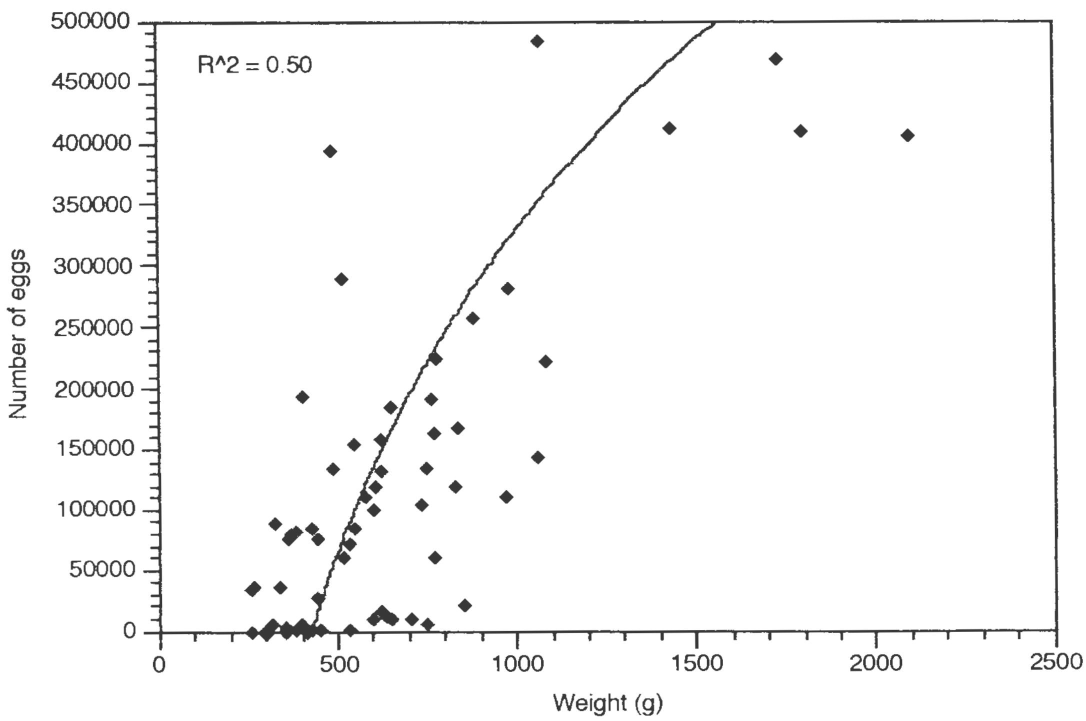


Figure 17: Snook fecundity to fish weight relationship.

The number of eggs to weight increased up to 1730 g (75 cm total length, est 6.1 years of age), although this decreased slightly with the single specimen of 2100 g, (88cm, 11 years).

Some remnant oöcytes were found after spawning, and these were not counted.

8.2.6. Oöcyte Diameters

The most advanced oöcyte diameter class (>0.40 mm) is shown in Figure 18 as a percentage of the total eggs count, with peaks in December/January indicating the spawning period.

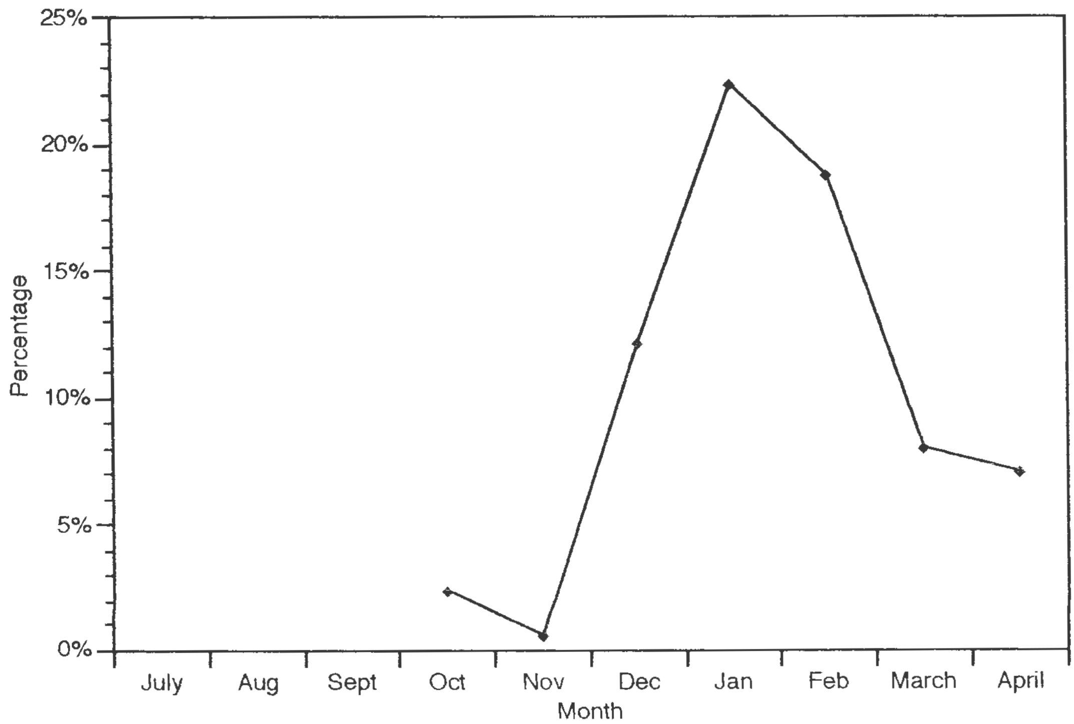


Figure 18: Frequency of stage V eggs (>0.40-0.50 mm).

MOD values indicated a spawning period from early December to the of end January/early February.

The largest oöcytes found were approximately 0.50 mm diameter, yolked, and probably close to ovulation; however no running ripe females were caught to confirm this. The following approximate oöcyte diameters were determined:

<0.10 mm

>0.10-0.25

>0.25-0.40

>0.40-0.50

Large oöcytes (>0.40) were found from October. Oöcytes of all four sizes were present prior to spawning, with medium oöcytes (< 0.25 - 0.40 mm) more numerous than the larger and smaller sizes. Some large oöcytes (>0.40 mm) were found in October, however only a few were found in November (Figure 19). The reason for this is not known, and could be due to biased sampling or lack of sufficient numbers of females. This is unlikely, as sufficient numbers of females (37 mature specimens) over a large spread of length frequency distributions were collected during November. Taking the presence of numbers of large oöcytes to indicate spawning, it is clear that late November to early February is the spawning season. There is a sharp drop of all oöcytes sizes from January.

These results and the monthly changes in MOD's, indicates that the species is a serial spawner, probably with multiple batches of eggs spawned during the spawning season.

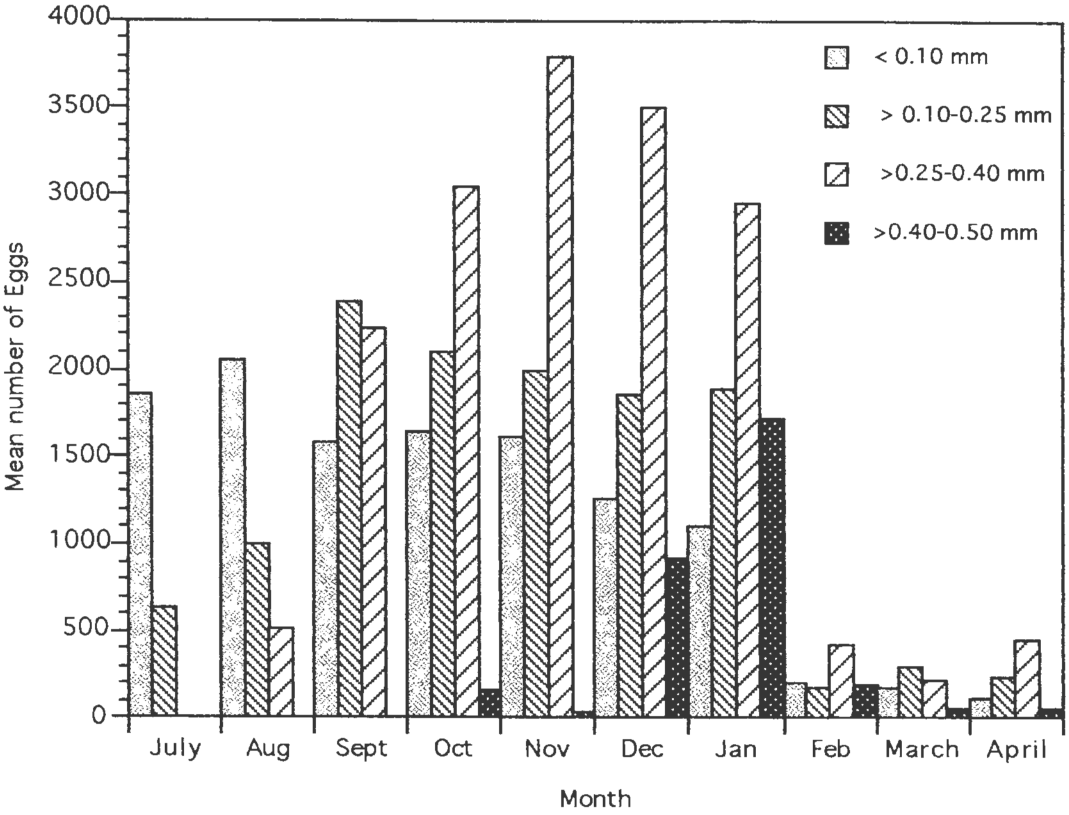


Figure 19: Mean number of eggs in each size oöcyte class for the snook.

There appears to be a positive relationship between egg diameter and fish length, with most oöcytes larger than 0.40 mm found in fish lengths over 55 cm, with only four females less than 55 cm having eggs in this size range. These were found in December and January, during the height of the spawning season. The smaller sized fish had less developed oöcytes than the larger fish. Figure 20 gives the breakdown of the number of >0.40 mm eggs by month for the +55 cm and -55 cm length groups of the females.

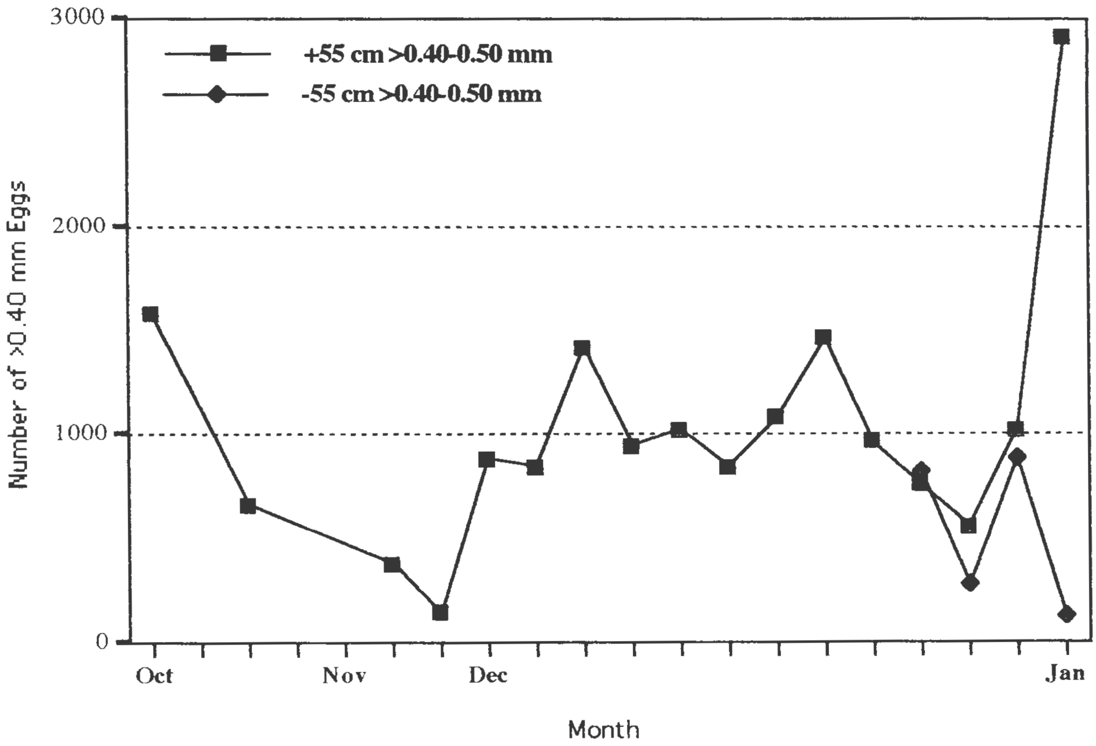


Figure 20: Number of >0.40 mm oöcytes for female fish lengths of +55 cm and - 55 cm.

8.2.7. Sex Ratio of Catches/Ontogenetic Variation

447 specimens were sexed, of which 165 were males and 282 females, ie a female to male sex ratio of 1.6 : 1. The chart of the sex ratio on a monthly basis is shown in Figure 21. As the sampling was random, it indicates that the sex ratio is not 1 : 1

for various times of the year. There was a significant bias towards females for October and December 1993, and March 1994, although these months will not include spawning fish. For the other months there was little significant difference between the ratio of males and females.

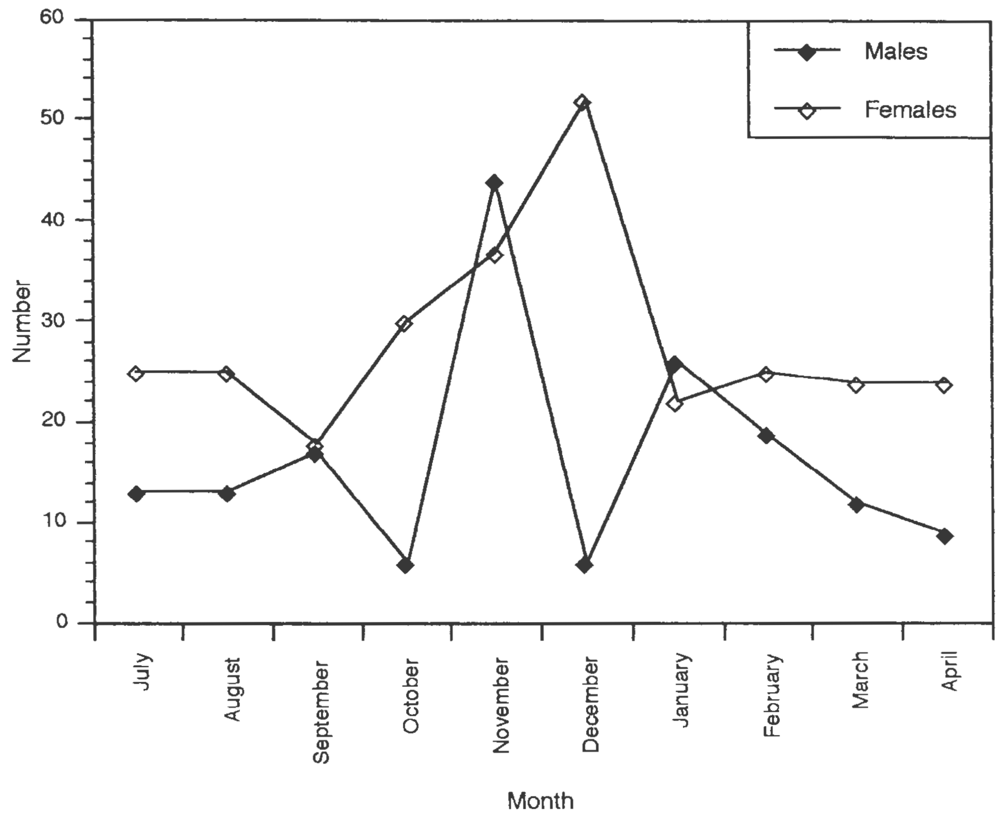


Figure 21: Number of males to females by month.

The changes in sex ratio with length showed a consistent pattern with the smaller length classes consisting of male fish and the larger length classes biased towards females. The males and females were separated into -55 cm and +55 cm size groups (Figure 22). Males of +55 cm length only occurred from September to February, and the -55 cm length group varied greatly during the year. Females of -55 cm had even distribution throughout the year, with the +55 cm length group peaking from November to February.

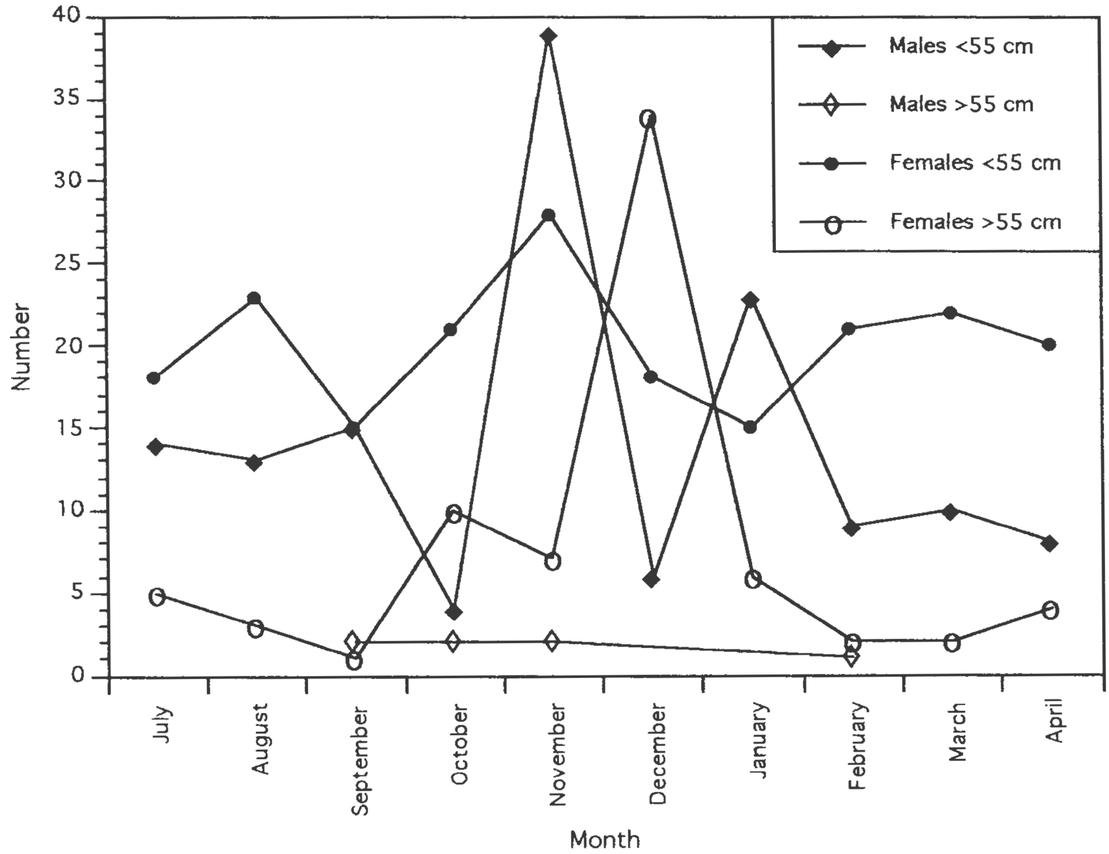


Figure 22: Number of males and females, +55 cm and -55 cm length groups.

8.3. Stomach Contents

Table 4 details the stomach contents for the total number sampled and the break-down for male and females.

Table 4: Stomach contents number and percentage, males & females.

Total Sexed and Unsexed			*Males*		*Females*	
Total Number Sampled	625	%	165	%	282	%
Stomach Contents	318	50.9	77	46.6	173	61.0
Teleosts	254	80.0	68	88.0	147	85.0
Crustaceans	47	14.8	7	9.0	18	10.4
Cephalopods	3	1.1	1	1.3	1	0.6
Other	13	4.1	1	1.3	7	4.0
Total	318	100	77	100	173	100

Of the 625 stomach contents examined, 308 were empty (49%). Teleosts comprised 46% of their prey of the snook. Greasyback prawns (*Metapanaeopsis* species, 10-20 mm carapace length; also known as coral prawns) were also an important food source, especially from May-July and also during December-January. Almost all of the prawns found in the stomachs of snook were taken between Port Wakefield and Port Adelaide at 4 - 5 metres water depth, in seagrass beds which are the habitats of this species (Kialola et al, Aus. Fish. Resources, 1993). Of the stomachs examined, 51% contained prawns.

Of the fish identified, pilchard *(Sardinops neopilchardus)* found in the Spencer Gulf, were the most numerous. (Table 5).

Figure 23 gives a graphic view of stomach contents by month.

From personal observation of catches, they did not regurgitate food at the moment of capture.

Table 5: Identified species found in stomachs of the snook.

Common Name	*Scientific Name*	*No.*	*Comments*
Greasyback Prawn	*Metapanaeopsis* species	46	May-June, Dec-Jan
Southern calamary	*Sepioteuthis australis*	2	
Pilchard	*Sardinops neopilchardus*	28	Nov, Feb
Southern sea garfish	*Hyporhamphus melanochir*	6	mostly Oct
Yelloweye mullet	*Aldrichetta forsteri*	3	
Weedy whiting	*Haletta semifasciata*	2	
Hardyhead	*Pranesus ogilbyi*	2	
Tommy rough	*Arripis georgianus*	1	

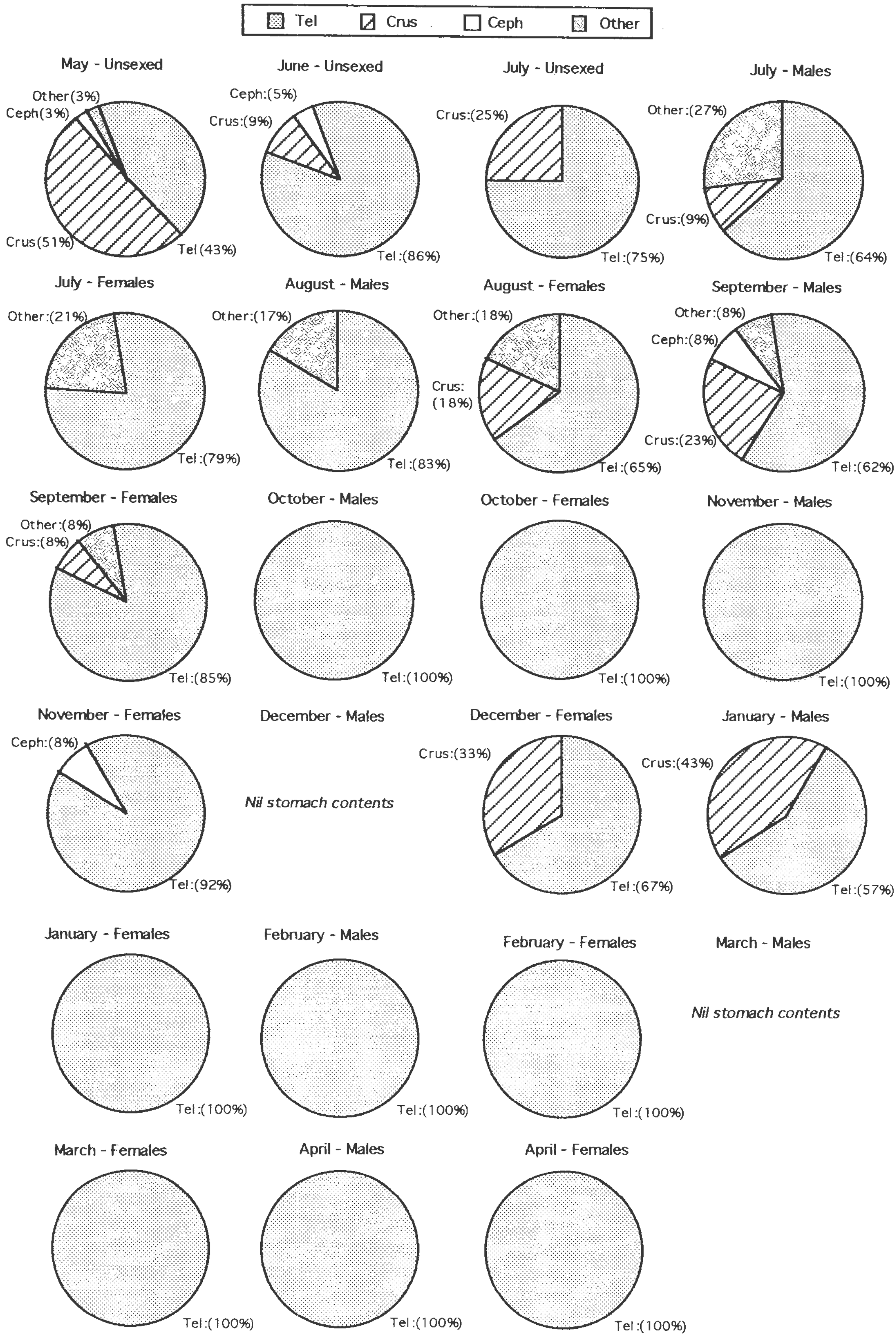


Figure 23: Seasonal composition of snook stomach contents.

Evidence of bottom feeding is shown by the presence of garweed and other weed (*Amphilibolis*, *Zostera* and *Heterozostera* species). These were probably ingested while prey such as southern sea garfish were being taken.

Some of the teleosts found in the stomach were surprisingly large, as listed below:

Length of snook (cm)	Length of prey (cm)
37	10
43	16
46	13.5
47	14.5
50	10.5
52	11
54	14

The majority of the stomachs examined contained teleosts that were partly digested and this made identification impossible, except with otolith recovery and identification by other sources - an undertaking beyond the scope of this study.

The percentage of stomachs contents varied markedly from month to month. It should be noted that only 6 males were found during December and 9 during March; these all had empty stomachs.

A Spearman nonparametric correlation test was done to determine the male/female relationship, and the result is given in Table 6.

Table 6: Nonparametric Test for male and female stomach contents.

NONPARAMETRIC STATS	SPEARMAN RANK ORDER CORRELATIONS MD pairwise deleted			
vars.	Valid N	Spearman R	t (N-2)	p-level
Month & Males No	10	-.085367	-.24234	.8146137
Month & Male Stomach contents	8	.047619	.11677	.9108492
Month & Female No	10	-.196946	-.56818	.5855051
Month & Female Stomach contents	10	-.359763	-1.09058	.3072110

8.4. Otolith/Body Weight & Body Length Relationship

Figures 24 and 25 shows an otolith weight/fish total length relationship, and otolith weight/fish weight relationship for all snook sampled from May 1993 to May 1994. A significant positive correlation was found between the otolith weight fish length (r^2 = 0.81, Figure 24), and otolith weight and fish weight (r^2 = 0.82, Figure 25). This suggests that the weight of the otolith is proportional to the growth in length and weight of the individual. Otolith weight to fish length relationship is linear and the otolith weight to fish weight relationship is exponential.

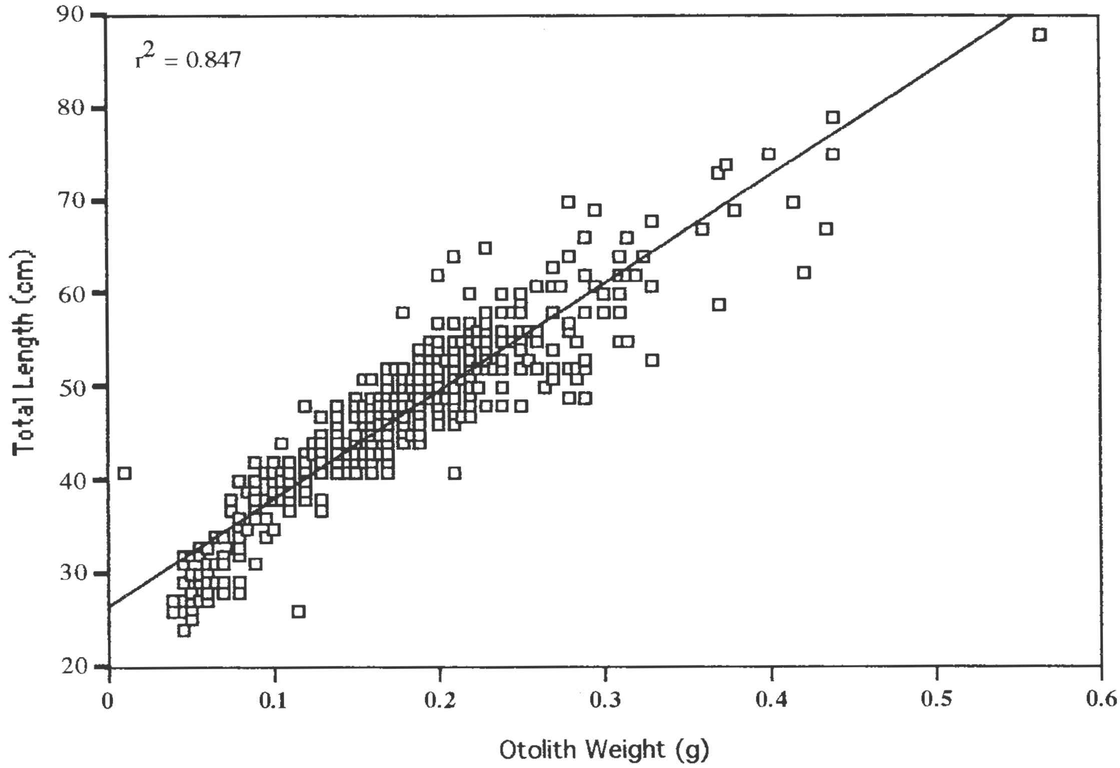


Figure 24: Otolith weight to total fish length relationship, N: 995.

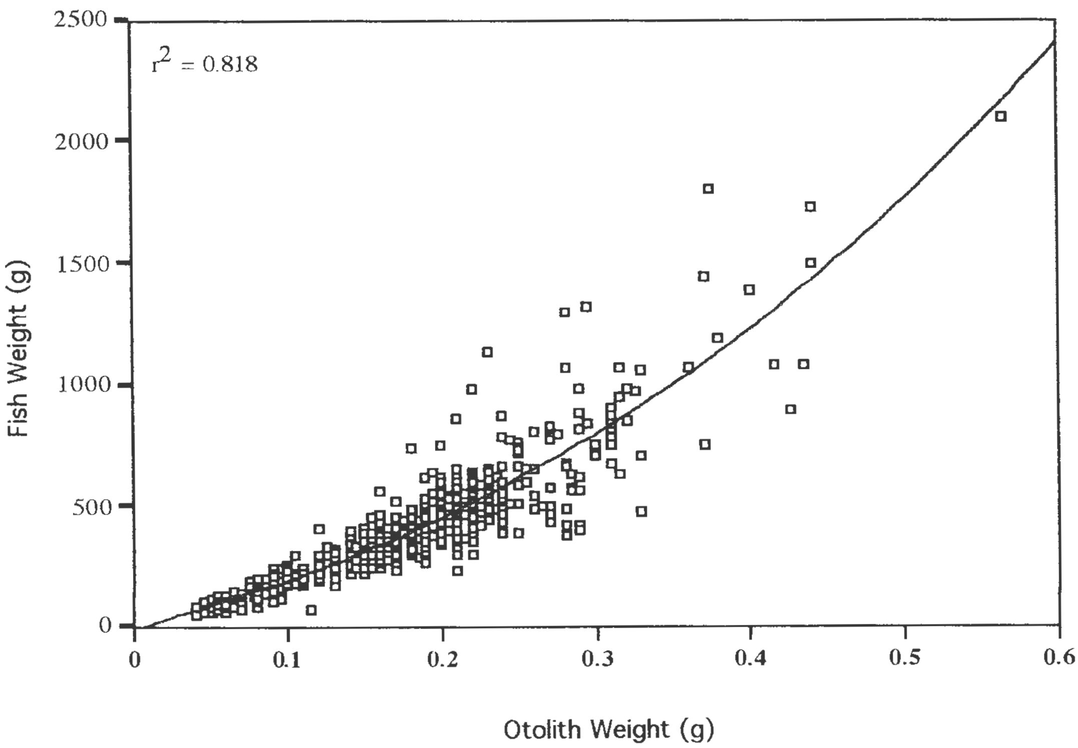


Figure 25: Snook otolith weight to whole fish weight relationship, N: 995.

8.5. Growth

8.5.1. Whole Sagittal Otoliths

Growth validation of length-frequency data was determined by counting the number of opaque zones for randomly selected otoliths. Table 7 gives the results of whole otolith examination and the resulting age classes for each fish. From the results it appears that one complete cycle of growth, consisting of the laying down of one opaque zone (spring/summer growth) and one translucent zone, (autumn/winter growth) can be taken as an annual cycle.

Table 7: Snook whole otolith opaque zone counts.

Month	*Sample No*	*Fish length*	*Fish wght (g)*	*Otolith wght (g)*	*Age Classes*	*Approx age from L/F dist (yrs)*
May	8	51	410	0.71	3+	3.3
	24	41	230	0.21	1+	2.4
	31	42	262	0.13	2+	2.4
	42	45	360	0.17	2+	2.6
June	60	58	716	0.25	4+	4.0
	77	41	260	0.15	1+	2.4
	88	46	345	0.16	3+	2.9
July	108	40	214	0.105	1+	2.2
	109	50	396	0.18	3+	3.1
	139	62	792	0.275	5+	4.5
	146	46	314	0.17	3+	2.7
	147	48	408	0.16	3+	3.0
Aug	160	56	650	0.255	4+	3.9
	170	36	155	0.095	1+	2.0
Sept	197	43	260	0.13	3+	2.6
	207	59	745	0.37	4+	4.4
	221	53	565	0.285	3+	3.5
Oct	226	41	240	0.13	2+	2.4
	238	45	335	0.15	3+	2.6
	260	61	840	0.295	4+	4.4
	260	50	445	0.17	3+	3.1
Nov	271	43	325	0.16	3+	2.5
	299	67	1065	0.36	5+	5.3
	312	44	305	0.20	3+	2.7
	328	49	355	0.20	3+	3.1
	341	37	255	0.13	1+	2.1
Dec	343	74	1800	0.375	6+	6.4
	345	53	665	0.24	3+	3.5

Month	*Sample No*	*Fish length*	*Fish wght (g)*	*Otolith wght (g)*	*Age Classes*	*Approx age from L/F dist (yrs)*
Dec	360	88	2100	0.565	9+	11.0
	367	47	320	0.14	2+	2.9
	380	62	810	0.31	5+	4.5
	383	44	300	0.14	2+	2.7
Jan	426	42	260	0.12	1+	2.5
Feb	475	51	428	0.12	3+	3.3
	492	32	105	0.07	1+	1.75
	509	75	1380	0.40	7+	6.6
March	532	40	220	0.09	1+	2.4
	538	60	750	0.31	4+	4.2
	572	43	250	0.13	3+	2.5
April	587	55	600	0.24	4+	3.7
	612	41	230	0.10	1+	2.4

8.5.2. Sectioned otoliths

The interpretation of the whole otolith has to be treated with caution as this technique has under-estimated the age of the fish compared with transversally sectioned otoliths (Power, 1978; Beamish, 1977a, b; Campana, 1984; Fujiwara & Hankin, 1988). From the results, there are inconsistencies of the age classes. Therefore these results were not used for any ageing/validation work, with only the transversally sectioned otoliths used to check the validity of the length-frequency data.

Otoliths from both sexes for each month of the study period were examined, and 387 otoliths sectioned. Table 8 gives the age classes results of this examination. Four otoliths were unreadable and not used. The transverse sections displayed a central dense core region and alternating sequences of narrow, dark opaque increments separated by wider translucent zones. Both zones were easily discernible.

Table 8: Sectioned otoliths opaque zone age classes for the snook, N=388.

Age Class Month	0+	1+	2+	3+	4+	5+	6+	7+	8+	9+	10+
Jan	1	4	16	5	4		1	1			
Feb	2	5	17	8	5	2		1			
March	5	6	15	1		1					
April	4	10	11	5	1						
May	4	6	12	1	1						
June	1	2	9	5	1	1					
July		5	9	7	2	1					
Aug	1	5	14	7	2						
Sept	1	6	13	3	2	1	1				
Oct	2	8	15	3	1	2	2	1			
Nov	1	11	12	11	7	4	2	2			
Dec	1	10	17	9	7	5					1

The results of the monthly mean marginal increment measurements indicates the formation of the translucent zone from February (Figure 26). This is at the end of the spawning period, and it was concluded that the translucent zone was formed in autumn/winter and the opaque increment in spring/summer.

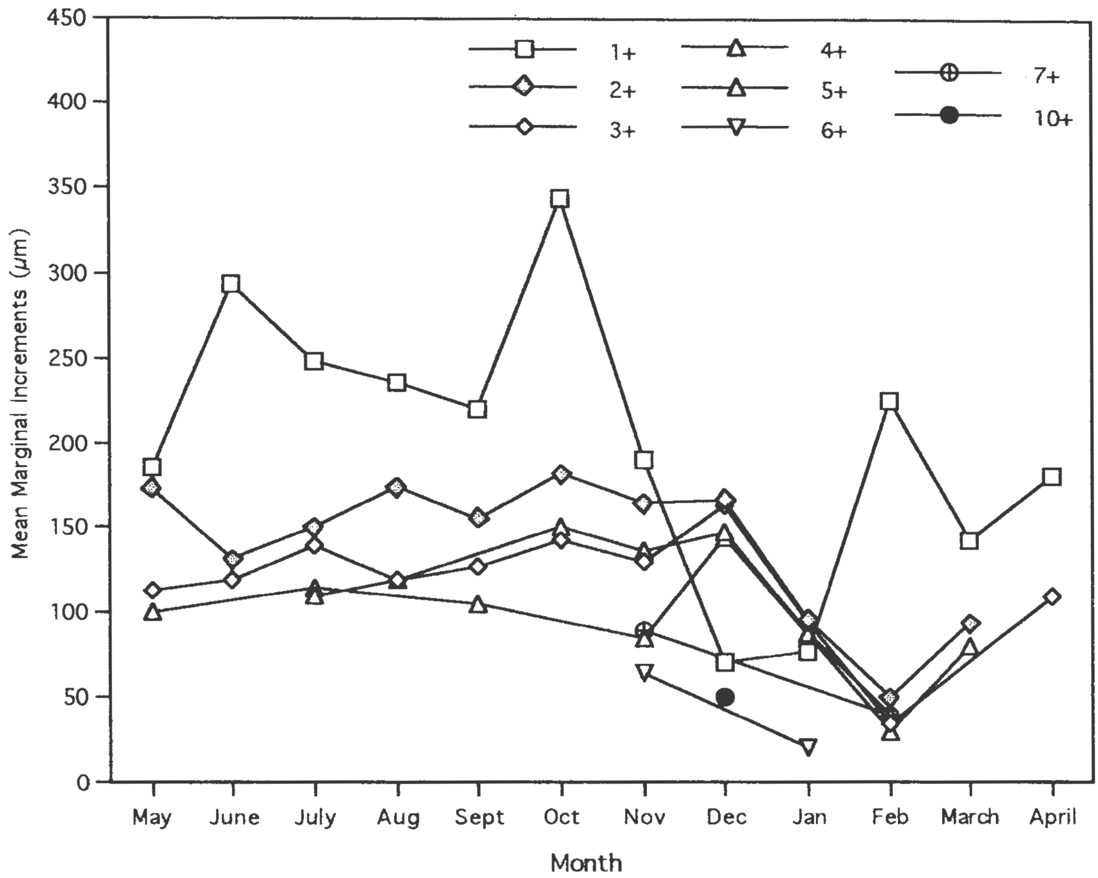


Figure 26: Marginal increment measurements indicating the distance measured from the last opaque increment to the edge of the otolith. N: 387.

All age class translucent zones appear to form from February, except for age class 1^{+}, where the monthly increments varied considerably and the minimum increment was during December. Note that there were no specimens in age classes 8^{+} and 9^{+}, and only one female specimen for age class 10^{+}.

From the data it appears that the 1^{+} fish start depositing an opaque increment from December, making makes this particular age class difficult to interpret. For analysis purposes only age classes 2^+ and 3^+ were used, due to small numbers represented in the other age classes.

A t-test showed there was no change in male/female differences between age classes $2^+$and 3^+ for weight and length (Table 9), and no interaction for length and weight (P: > 0.1).

Table 9: t-test for otolith male and female 2^+ and 3^+ age classes.

Age Class	Criteria	Sex	N	mean	SE	t	P
2^+	Length	Male	72	41.7	2.5	3.67	0.0005
		Female	88	48.0	3.0		
	Weight	Male	72	364	71	2.46	0.017
		Female	88	387	71		
3^+	Length	Male	39	50.2	2.8	2.69	0.011
		Female	46	58.0	3.4		
	Weight	Male	39	457	83	1.92	0.062
		Female	46	523	108		

Table 10 gives the mean lengths in each age class. These were used for the FISHPARM application to fit the von Bertallanfy growth equation.

Table 10: Mean lengths in each age class for males and females.

Males			*Females*		Combined Sexes	
Age Class	Mean lgth	N	Mean lgth	N	Mean lgth	N
0^+	31.1	16	33.0	11	32.0	27
1^+	33.2	33	36.0	37	34.4	70
2^+	41.7	72	48.0	88	45.0	160
3^+	50.2	29	58.3	36	54.2	65
4^+	56.7	15	64.2	18	60.5	33
5^+	63.7	2	69.8	16	66.6	18
6^+	-		75.0	6	75.0	6
7^+	-	-	83.6	5	83.6	5
8^+	-	-	-	-		
9^+	-	-	-	-		
10^+	-	-	88.0	1		1

FISHPARM gave growth parameters for the males that were too high (Table 11). This could be due to there not being any males in age class 6+ and older, even though the mean lengths for each age class is less than the females and should indicate slower growth. Therefore the results for the males cannot be used with confidence. The ELEFAN and Wetherall results are also given as a comparison.

The females and the combined data growth results compares closely with the ELEFAN and Wetherall methods (Section 8 below).

Table 11: Snook: FISHPARM growth parameters based on the size at age estimates. ELEFAN and Wetherall results are given for comparison.

Males			*Females*			*Combined Sexes*		
FISHPARM								
L_∞	K	t_o	L_∞	K	t_o	L_∞	K	t_o
129.0	0.096	-1.12	96.7	0.215	-0.27	103.0	0.175	-0.48
ELEFAN								
89.9	0.205	-	98.0	0.240	-	97.4	0.230	-
Wetherall								
						98.6		

Figure 27 gives the von Bertalanffy growth curves for the males and females as well as the combined data.

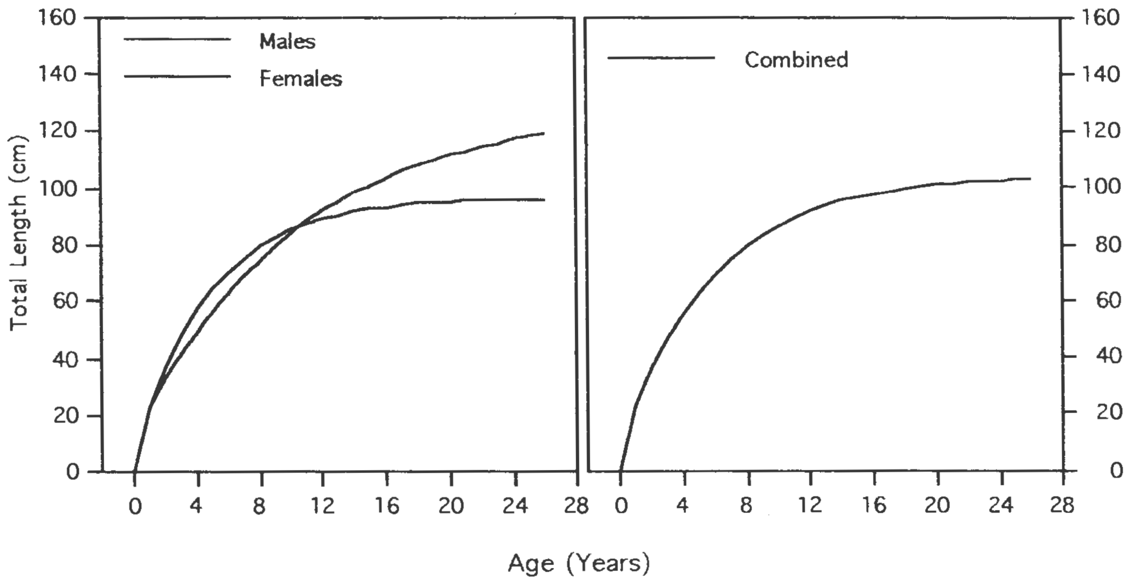


Figure 27: Snook von Bertalanffy growth curves for (left) males and females, and (right) combined.

8.5.3. Length Frequency Distribution

By the end of the study period a total of 955 specimens was collected, measured and sexed.

The size frequency distributions by month is given in Figure 28.

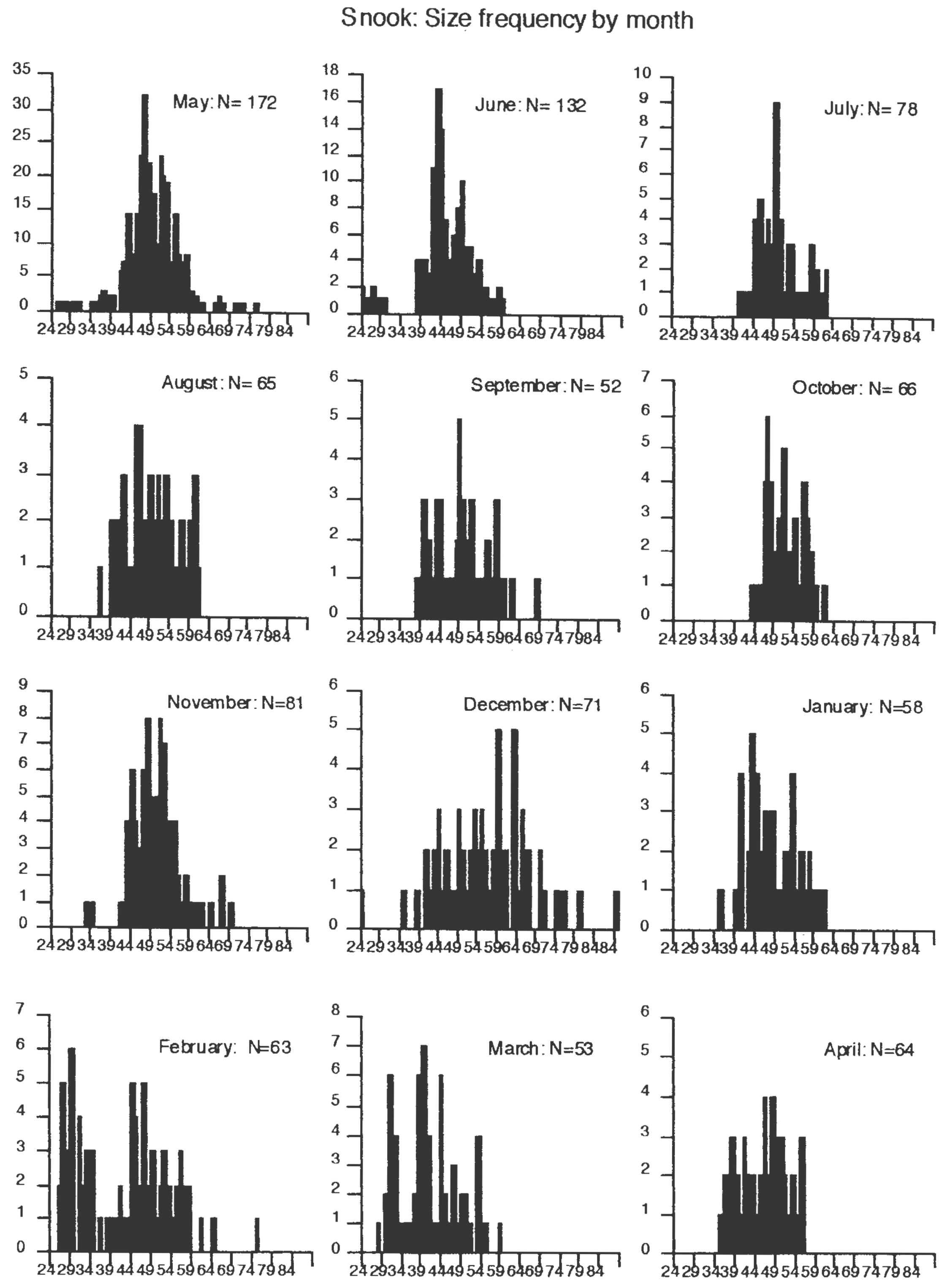


Figure 28: Snook size frequency distributions by month.

Total length frequency distributions of specimens collected from commercial fishers in Spencer Gulf and Gulf St Vincent, do not show any discernible age class modes for the different methods of fishing (trolling and haul net), but there is a major peak at 48.5 cm total length, (Figure 29). This compares with the peak of 48.8 cm for work previously completed (Bertoni, 1992). However the previous study included very few juveniles or undersize specimens. The range of fish is considerable - from 11.5 cm to 88 cm total length (including unsexed specimens). A separation of length frequencies by sex showed that the size range of males (38 to 64 cm) was less than that of females (38 to 88 cm). The mean for males was 47 cm (2.8 years of age), and females 51 cm (3.1 years).

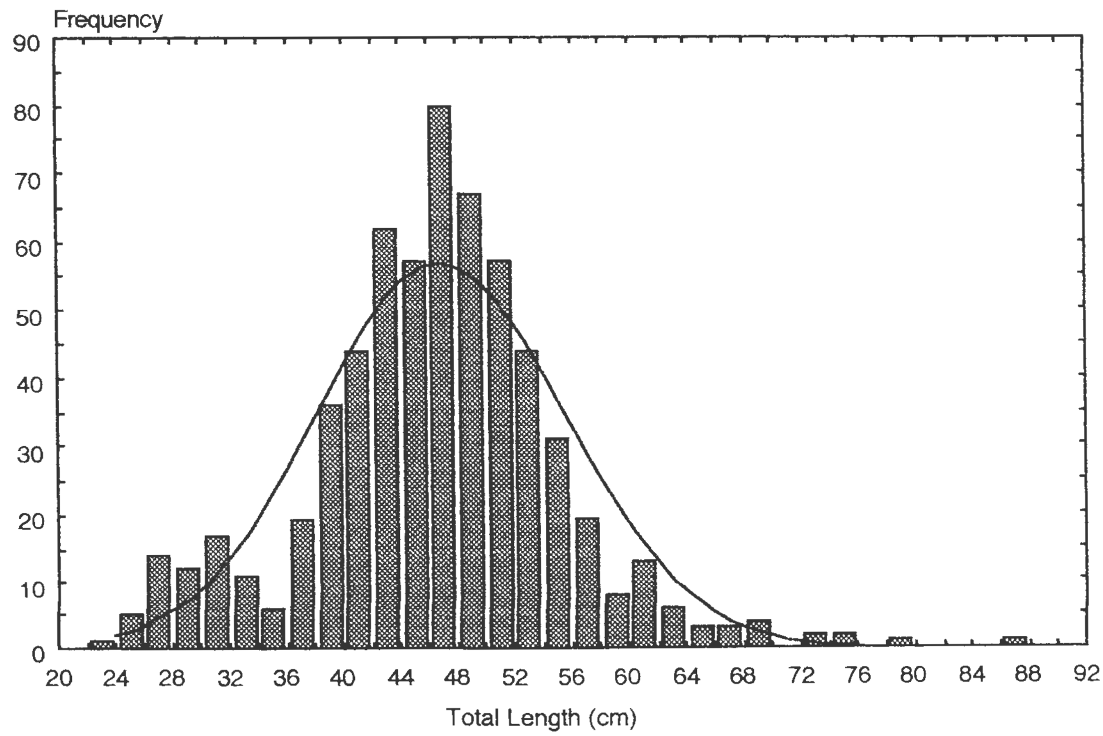


Figure 29: Snook Length Frequency Distribution for total study of sexed, unsexed & juveniles. A normal curve is superimposed. N: 955, Mean 48.5 cm, Std Dev 8.77, SE Mean 0.351.

Figure 30 gives the monthly mean lengths for males and females. Females were generally larger then males, and larger females were found prior to spawning, with a decrease in mean length after spawning. The mean size for males were relatively steady throughout the year.

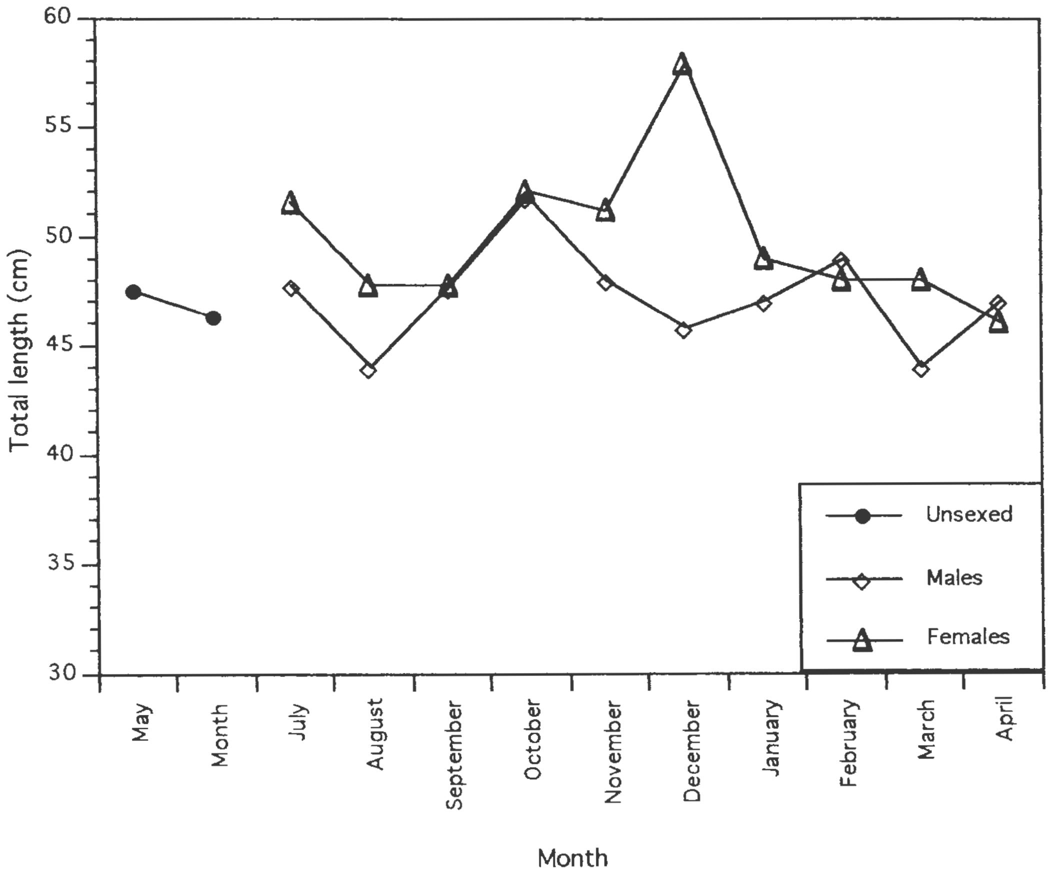


Figure 30: Snook monthly mean lengths for males and females.

Figures 31 and 32 shows the size distributions for males and females respectively. The distributions of the total study, and males and females separately is positively skewed as would be expected from the selectivity of commercial sampling.

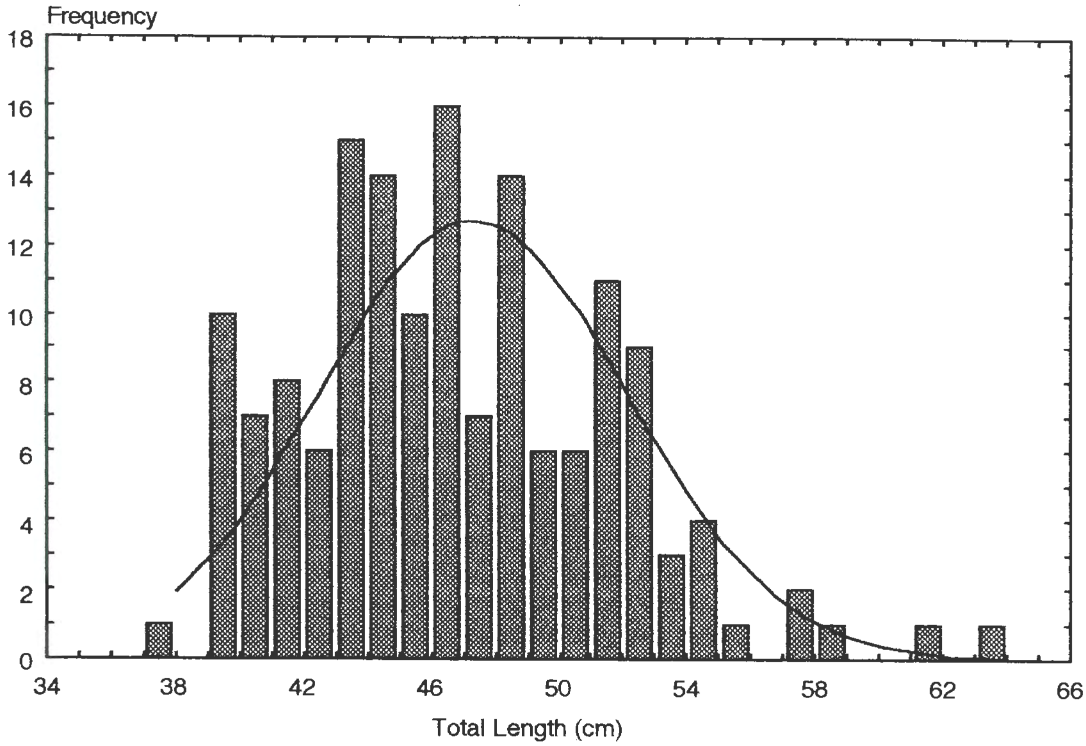


Figure 31: Snook male Length Frequency Distribution. N: 165, Mean 47 cm, Std Dev 4.80, SE Mean 0.388.

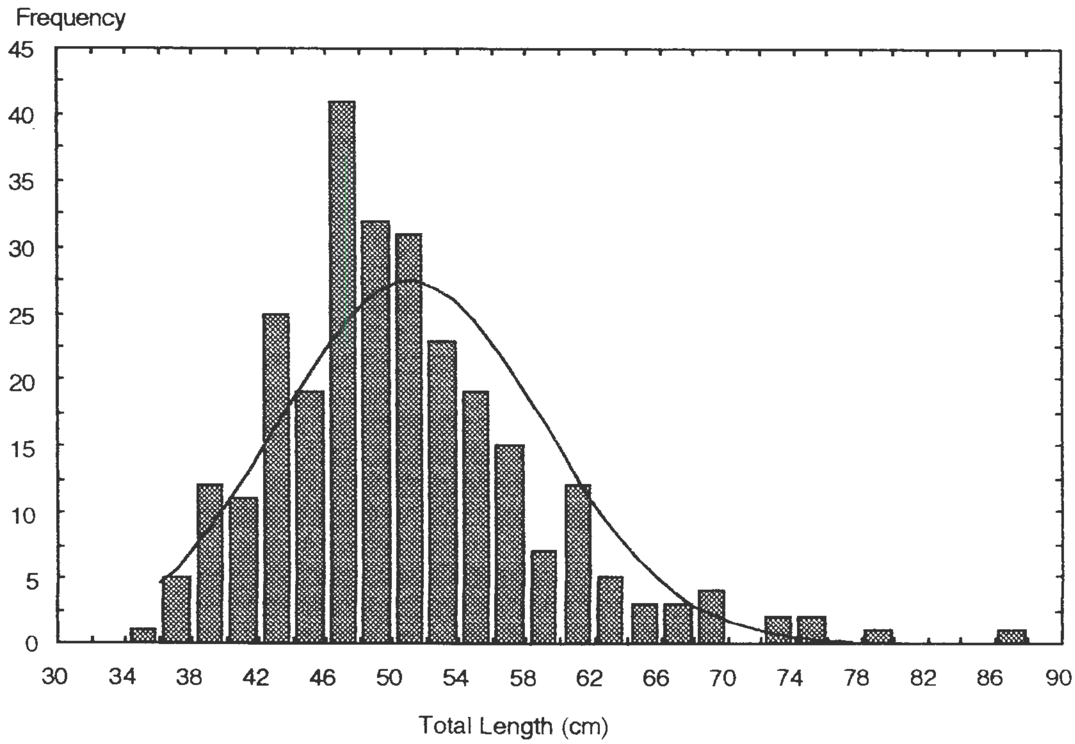


Figure 32: Snook female Length Frequency Distribution. N: 282, Mean 51 cm, Std Dev 7.95, SE Mean 0.480.

A determined effort was made during field trips to obtain as many juveniles and pre-adult (ie less than 42 cm) specimens as possible to ensure that adequate numbers of smaller or immature specimens were collected for the study. Figure 33 gives the length frequency distribution of the immature fish less than 42 cm total length.

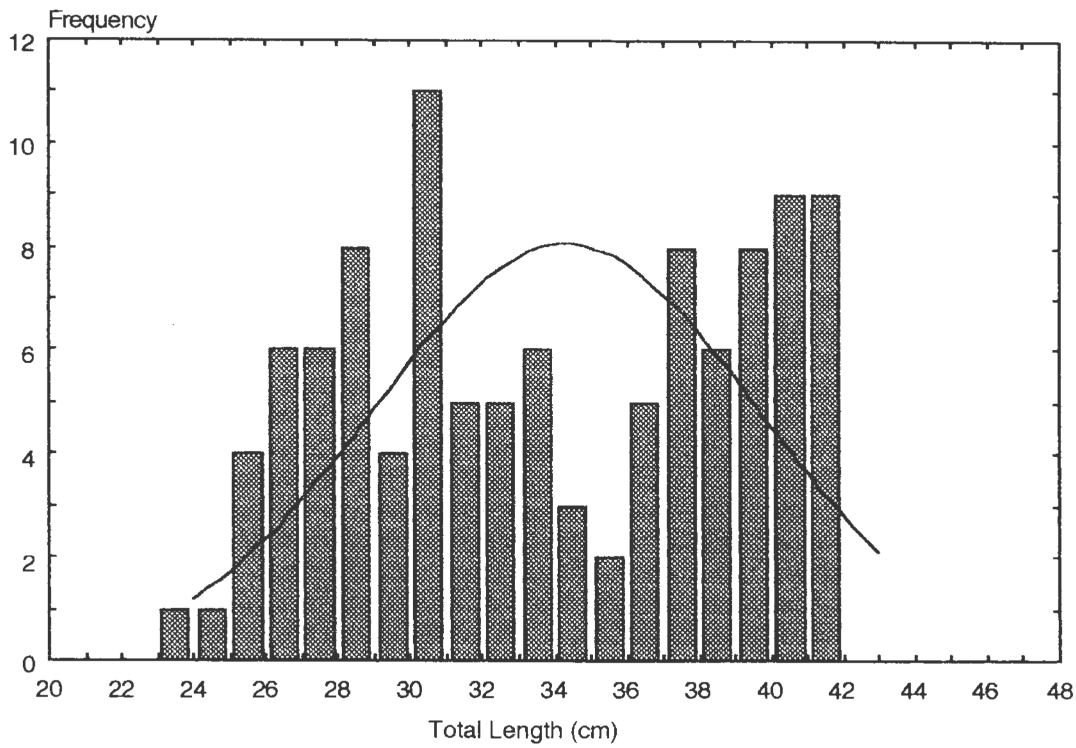


Figure 33: Snook juvenile/pre-adult Length Frequency Distribution. N: 94, Mean 34cm, Std Dev 5.287, SE Mean 0.511.

8.5.3.1. Length Frequency Analysis - ELEFAN I

8.5.3.1.1. Combined Data

ELEFAN I gave a mean value for L_∞ of 97.4 cm and a K value of 0.230/year for both sexes combined (Table 12). This compares favourably with the Wetherall plot of L_∞ 98.6 cm (Section 8.5.2.2.). See Figure 34 for the von Bertallanfy growth curve.

Table 12: ELEFAN Length Frequency analysis for combined length frequencies. Rn: Surface response number, indicates the "goodness of fit".

Run No.	*L_∞ (cm)*	*K*	*Rn*
1	97.1	0.233	.227
2	97.3	0.232	.227
3	96.6	0.230	.227
4	97.4	0.230	.227
5	97.3	0.230	.227
6	96.9	0.232	.226

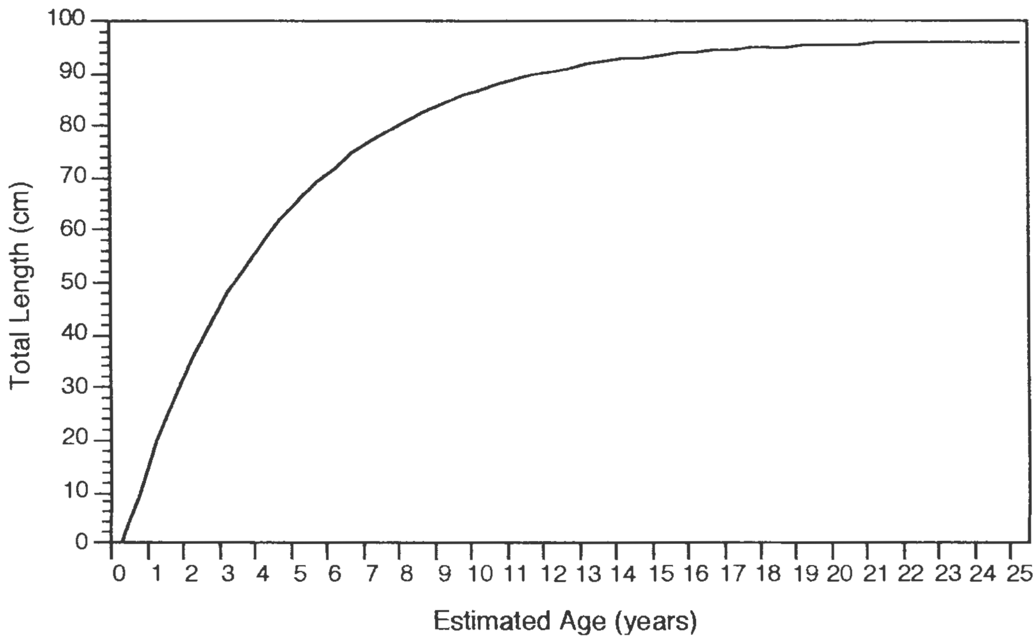


Figure 34: Von Bertalanffy chart for total fish, males females and juveniles/pre-adults: L_∞ : 97.4 cm, K: 0.230.

8.5.3.1.2. Males and Females

A two-way analysis of variance of adult length showed a significant effect of sex (P=<0.001) and some dependence on month (P=<0.05). See Table 13.

Table 13: Two-way ANOVA of adult lengths by sex and month.

ANOVA: Var 1-MONTH, Var 2-SEX

Effect	*df Effect*	*MS Effect*	*df Error*	*MS Error*	*F*	*p-level*
Month	9	74.5643	369	33.81742	2.20491	.0211816
Sex	1	625.1740	369	33.81742	18.48674	.0000219
M*S	9	77.2290	369	33.81742	2.28371	.0167769

Using ELEFAN I, males had a mean L_∞ of 89.9 cm and a K value of 0.205/year, and for females a mean L_∞ of 98.0 cm and a K value of 0.240/year. The males have a lower L_∞ and K values; this could be due to the males not being as well represented as the females with fewer large fish, and indicates a smaller maximum size as well as slower growth rate, Table 14.

The ELEFAN Length frequency histograms and growth curves for both sexes is given in Figure 35 and Figure 36 respectively. An age length key is given in Table 15.

Table 14: ELEFAN Length Frequency analysis for males and females. Rn: Surface response number, indicates the "goodness of fit".

Females				Males		
Run No.	L_∞ *(cm)*	*K*	*Rn*	L_∞ *(cm)*	*K*	*Rn*
1	98.7	0.250	.231	89.7	.210	.289
2	97.0	0.240	.237	89.2	.200	.189
3	98.4	0.240	.304	90.4	.205	.318

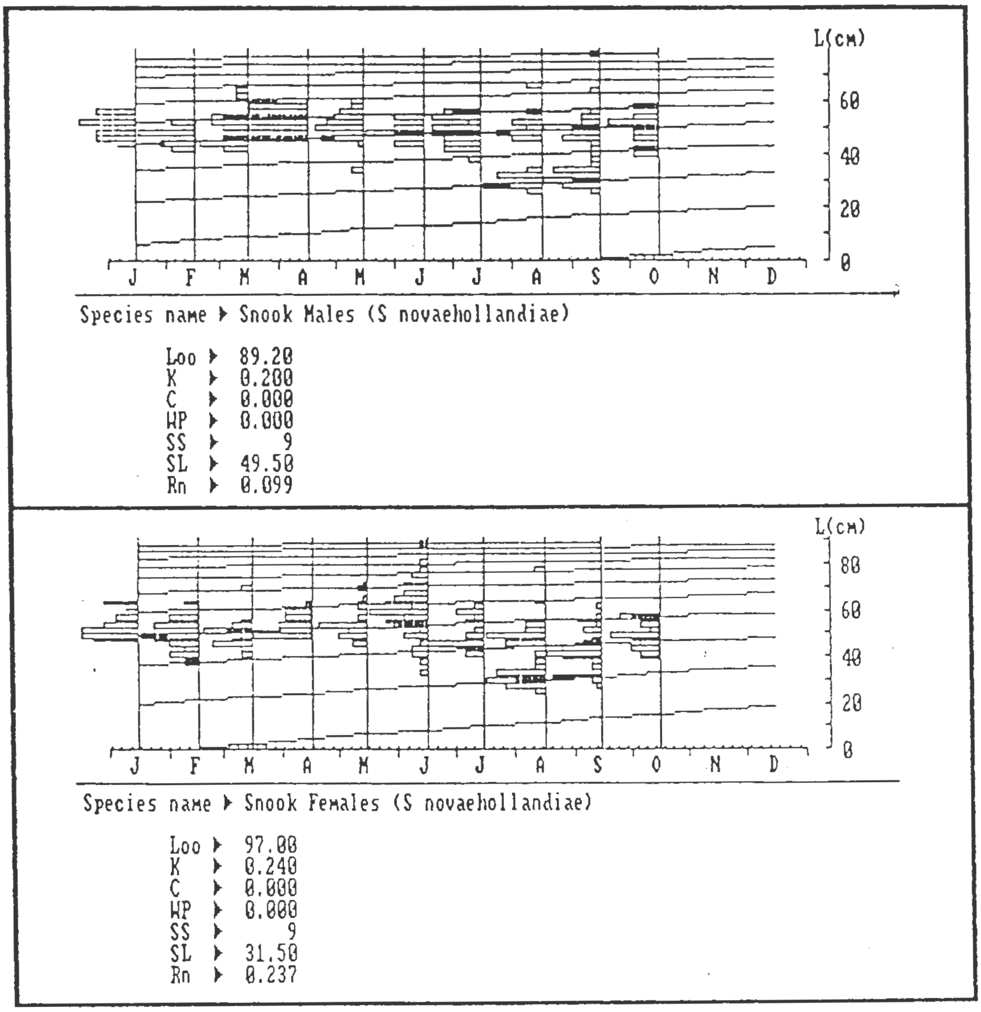


Figure 35: ELEFAN generated von Bertalanffy growth curves for snook, Run No. 2. Top: males and Bottom: females.

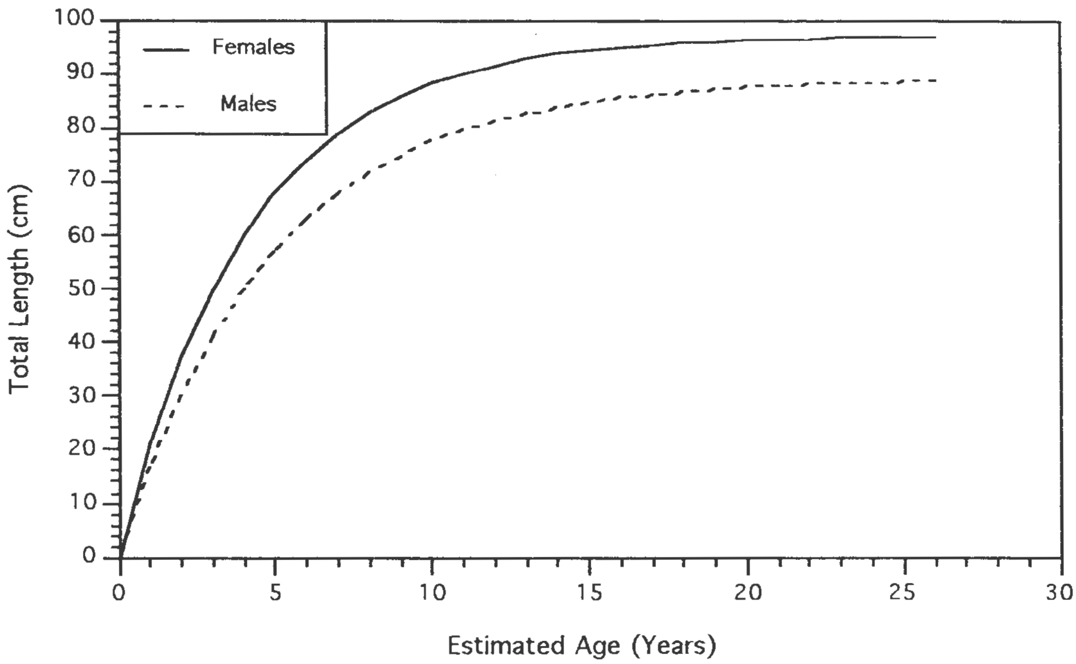


Figure 36: von Bertalanffy Chart for males (L_∞ 89.9 cm, K 0.205/year) and females (L_∞ 98.0 cm, K 0.240/year).

Table 15: Snook Age/Length Key for total study, and males and females separately.

Total Study		Males		Females	
Age	*Length*	*Age*	*Length*	*Age*	*Length*
1	19.81	1	16.53	1	20.70
2	35.54	2	30.00	2	36.98
3	48.05	3	40.97	3	49.79
4	57.98	4	49.91	4	58.86
5	65.88	5	57.20	5	66.78
6	72.15	6	63.13	6	72.02
7	77.13	7	67.96	7	77.92
8	81.09	8	71.90	8	81.78
9	84.24	9	75.10	9	84.81
10	86.74	10	77.72	10	87.20
15	88.70	15	82.08	15	91.35
20	91.60	20	85.72	20	93.20
25	92.49	25	88.67	25	95.76

8.5.3.2. Length Frequency Analysis - Wetherall

The combined length frequency data was entered into a Wetherall plot and 4 runs were completed to test the accuracy. A mean L_∞ of 98.6 cm and a mean Z/K value of 5.02 was obtained - comparable to ELEFAN I, and are similar to results obtained in Bertoni (1991). Table 16 below summarises the results, and Figure 37 gives an example of a Wetherall plot. The best fit was run number 1.

Unsuccessful attempts were made to fit a Wetherall plot to male and female data. The obtained L_∞ for both sexes were too low (70-80 cm) to be realistic. This was possibly due to gaps in the length frequency data, or the larger size classes not being well represented.

Table 16: Wetherall plots for the snook.

Run No	*L_∞ (cm)*	*Z/K*	*L_C (cm)*	*Z*	*r^2*	*Cut-off*
1	97.9	4.42	26.5	1.38	0.594	29
2	96.6	4.79	27	1.57	0.579	30
3	98.7	5.21	29	1.52	0.560	31
4	100.3	5.69	26	1.32	0.544	32
Mean						
	98.6	5.02	27	1.45		

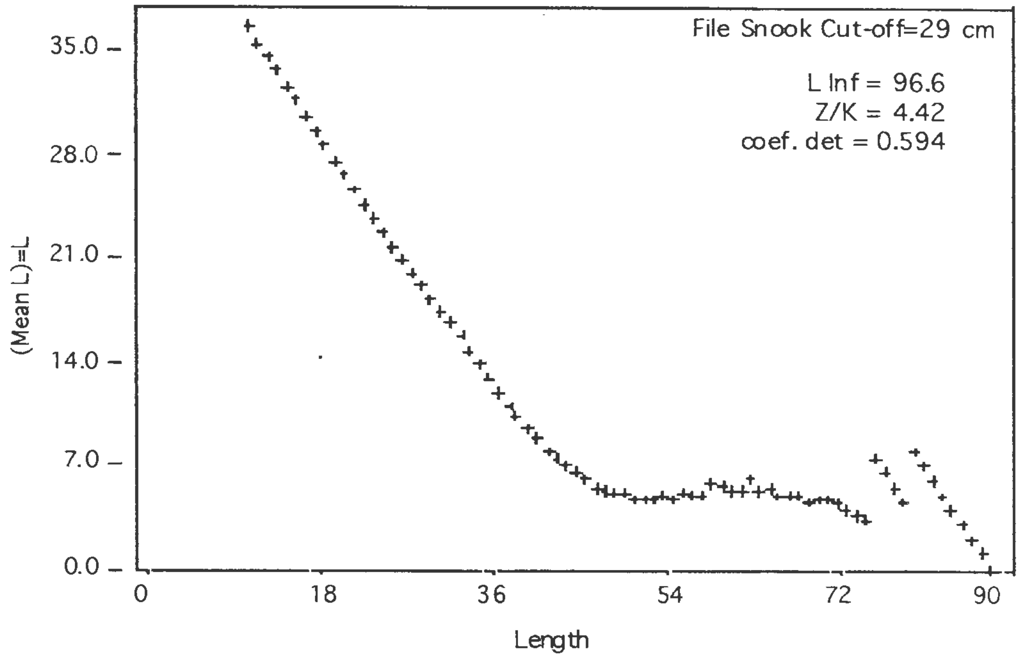


Figure 37: Plot showing an example of a modified Wetherall Plot (Run No. 2).

Of the total specimens collected for the year, 85% ranged from 42 cm and 62 cm total length, ie from approximately 2.4 to 5 years of age. The oldest male found was aged 6 years (64 cm total length) and the oldest female was aged 11 years (88 cm). This is a significant difference in the ages of fish sampled (t-test; P:>0.50); however the reasons for this is not known.

The numbers of fish for age classes and sex is given in Table 17 below. In age class 2 there are approximately equal numbers of males and females, but females are more numerous than males from age class 3 and up, with no males found above 6 years of age.

Table 17: Numbers and percentages of males and females found in each age class. N: 447.

Est Age (years)	Males			Females		
	No.	% of Males	% of Total	No.	% of Females	% of Total
2	121	73.3	27.0	135	48.9	30.3
3	37	23.0	8.5	97	34	21.5
4	4	2.4	1	33	11.2	7.2
5	2	1.2	0.6	10	3.6	2.3
6	1	0.5	0.4	5	1.7	1.1
7				1	0.3	0.25
8						
9						
10						
11				1	0.3	0.25
Total:	165	100	37.5	282	100	62.5

Figure 38 gives the percentages of males and females in each age class.

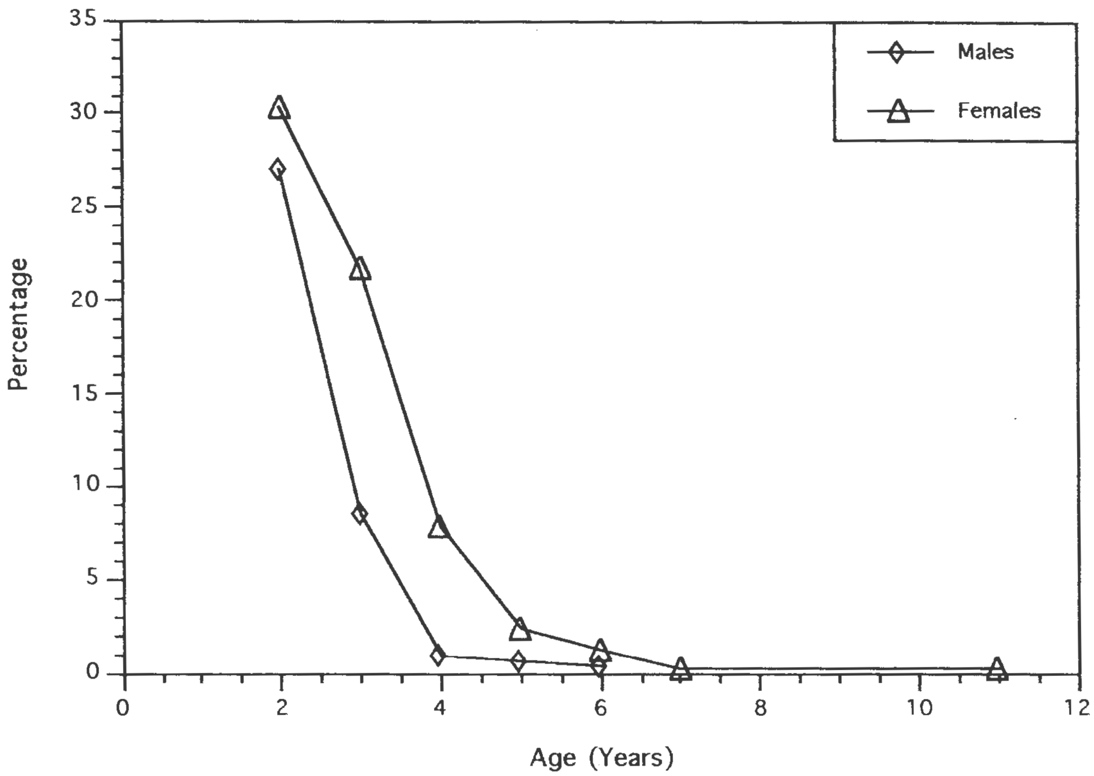


Figure 38: Percentage of males and females in each age class, May 1993 to May 1994.

8.5.4. Selectivity and Length at First Capture.

The Wetherall plot also determined the length at first capture, L_c, and this is given for all data in Figure 39, (run number one in Table 16 above). The mean of the 4 runs in Table 16 is 27 cm. The L_c is 26.6 cm (broken line at P=0.5, cutting the logistic curve), from a 3 cm net being used by the haul netters. Although only few pre-adults (<42 cm) are landed by the trollers, using the troll data gave a logistic selectivity curve of 39 cm total length.

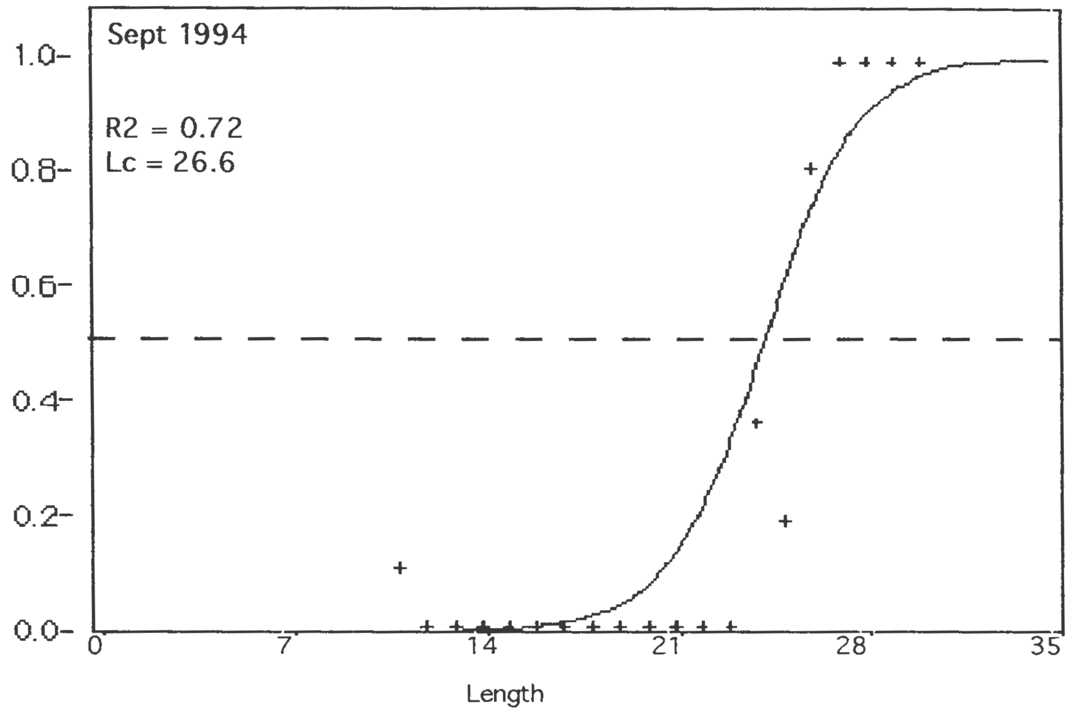


Figure 39: Logistic selectivity curve for all snook using a 3 cm power haul net (N = 955).

8.5.5. Length Weight Relationship

8.5.5.1. Adults

A length weight relationship for males and females are as follows:

Males: $W = 0.0016\ L^{3.21}$

Females: $W = 0.0020\ L^{3.13}$

This is similar to the other species in the family where *b* is between 3.05 and 3.30 (Williams, 1965; Premalatha &

Manojkumar, 1990), and compares with a = 0.0035, and b = 3.05 for unsexed specimens in Bertoni (1990/91).

The values obtained for b shows that growth for the species in weight relative to length is almost isometric, even though there is a difference in the length/weight relationships between the males and females (Figures 40 and 41).

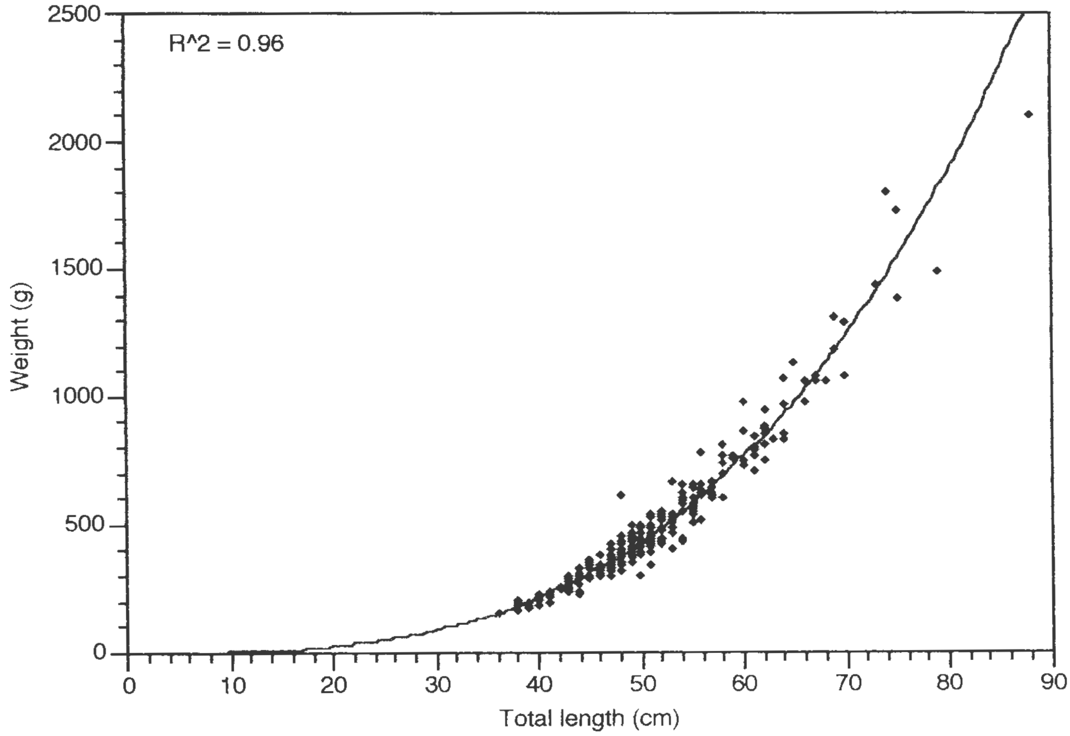


Figure 40: Snook females length/weight relationship. N: 282.

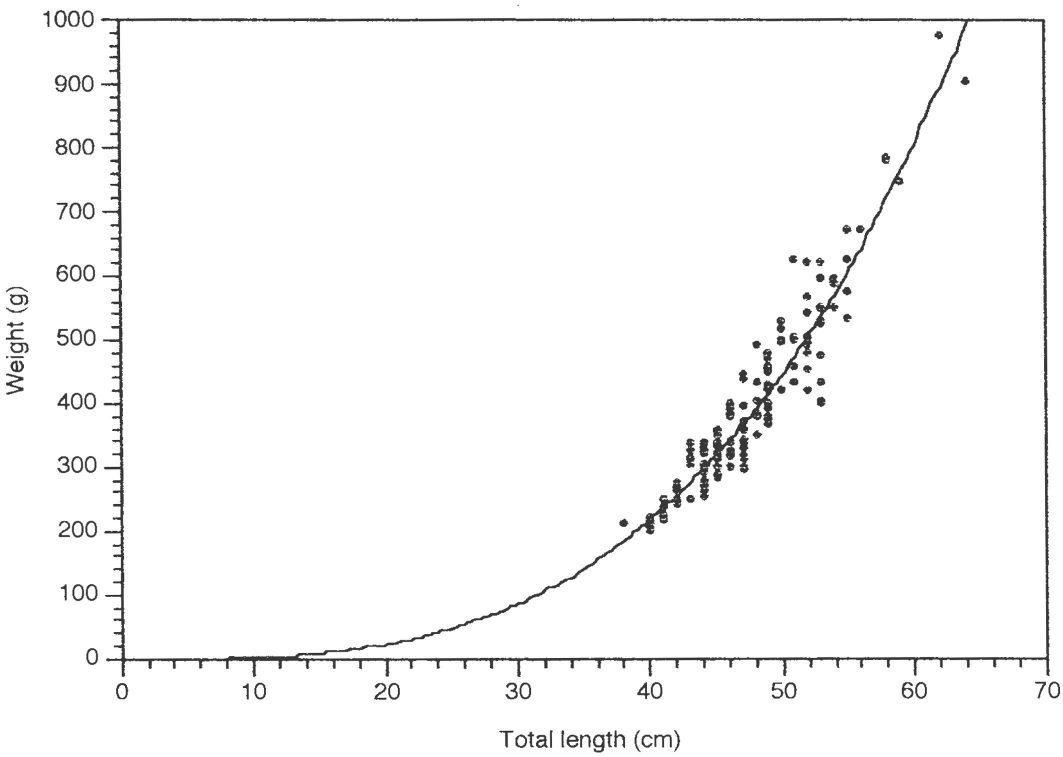


Figure 41: Snook males length/weight relationship. N: 165.

There is a small difference between the regression for the sexes although this is not conventionally significant (t test; P: <0.1). The estimated weights at given lengths were calculated separately, and using the length weight data and the growth estimates, the following approximations of weight and length at age can be estimated (Table 18). A comparison table of work previously completed (Bertoni, 1991) is included.

Table 18: Snook age length/weight key.

Males 1993/94			*Females 1993/94*			*1990/91 (Unsexed)*		
Age in Years	*Tot length (cm)*	*Weight (g)*	*Age in Years*	*Tot length (cm)*	*Weight (g)*	*Age in Years*	*Tot length (cm)*	*Weight (g)*
1	17	20	1	20	20	1	22	30
2	30	90	2	36	130	2	39	175
3	41	270	3	48	370	3	51	450
4	50	470	4	58	650	4	61	750
5	57	700	5	66	1050	5	69	1150
6	63	1000	6	72	1300	6	75	1500
7	68	1220	7	77	1650	7	79	1700
8	72	1500	8	81	2000	8	83	2050
9	75	1700	9	84	2150	9	85	2200
10	78	1950	10	87	2350	10	87	2400
12	82	2200	12	90	2700	12	91	2700
15	85	2500	15	93	2900	15	93	2900
20	88	2800	20	95	3200	20	94	3100

Based on the length weight relationship, W_∞ of the species is approximately 3400 g. The Australian gamefishing record for snook is 109.2 cm with a weight of 5600 g (Hutchins and Swainston, 1986).

8.5.5.2. Juveniles/Pre-adults

Due to the slightly different growth rates, the length weight relationships for juveniles and pre-adults (specimens below 42 cm) were determined separately, (Figure 42) and is of the form:

$$W = 0.0021\ L^{3.14}$$

This indicates that in common with other teleost species, the snook grows almost linearly in the early pre-adult phase.

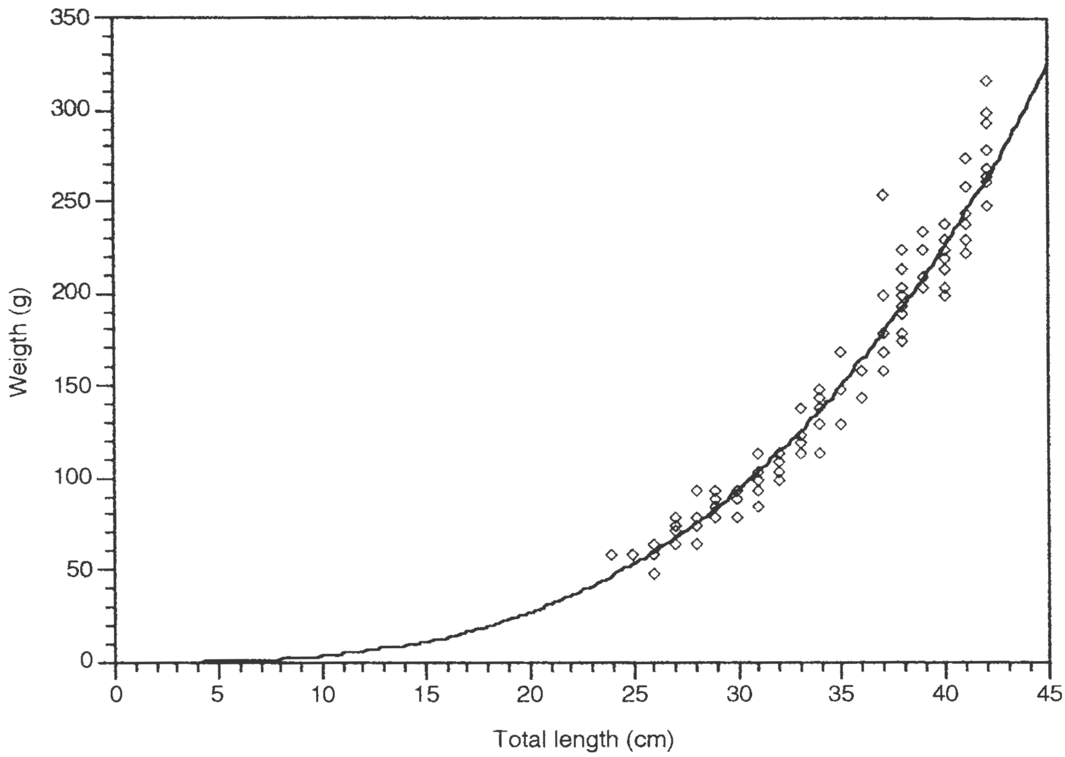


Figure 42: Snook length weight relationship for juveniles and pre-adults. N: 94.

8.5.6. Length/Age at First Maturity

94 immature and pre-adult specimens were taken during the study period.

The smallest fish collected during the study period measured 11.5 cm total length, weight 5.43 g; this equates to an age of approximately 0.7 years. This specimen was found in Barker Inlet of the Port River during fine net surveys in early March, 1994. No fry were found, and extensive fine net surveys taken in conjunction with the Aquatic Sciences section of the South Australian Research and Development Institute (SARDI, Jones, personal communication, 1994) in intertidal and estuarine waters over sand and seagrass beds have failed to find any fry and only the single juvenile mentioned above. These areas included mangrove tidal creeks as well as sheltered bays in Gulf St Vincent, from Port Adelaide up to the Port Wakefield area. However numbers of sexually immature or pre-adult fish (size range 24-40 cm total length, ages 1.2 - 2 years) has been found in the inshore areas around Port Wakefield in Gulf St Vincent, Whyalla and Port Lincoln in Spencer Gulf, and Coffin Bay on the west coast of Eyre Peninsula. Immature specimens have also been found with adult fish in both gulfs.

Males and females less than 40-42 cm total length showed little or nil gonad development, and did not progress past stage II for both sexes, although both sexes could be macroscopically identified from approximately 40 cm total length.

From the gonad studies it is estimated that size at first maturity is attained at approx 2.5 years of age when males are 40 cm total length, weight 190 g, and females are 42 cm total length, weight 240 g. The ovaries of all female fish smaller than 41-42 cm total length contained small oöcytes that did not ripen or increase in diameter during the study period (although this was not confirmed histologically). Therefore it is reasonable to estimate that all fish less than 40 cm are immature.

8.6. Total Mortality (Z)

Estimation of instantaneous total mortality rates using a length converted catch curve gave a result of Z = 0.73 for combined sexes, 0.79 for males and 0.72 for females (Figures 43, 44, 45). This compares with a Z = 2.83 and 2.24 for *S. obtusata,* a tropical species of barracuda found off India (Kasim & Balasubramanian, 1990; Somavanshi, 1989).

Instantaneous total mortality for snook was determined previously using length converted catch curves and are as follows: 1977: Z = 0.93, 1978: Z = 0.88, 1991: Z = 0.84. These were for unsexed specimens (Bertoni, unpublished data, 1992).

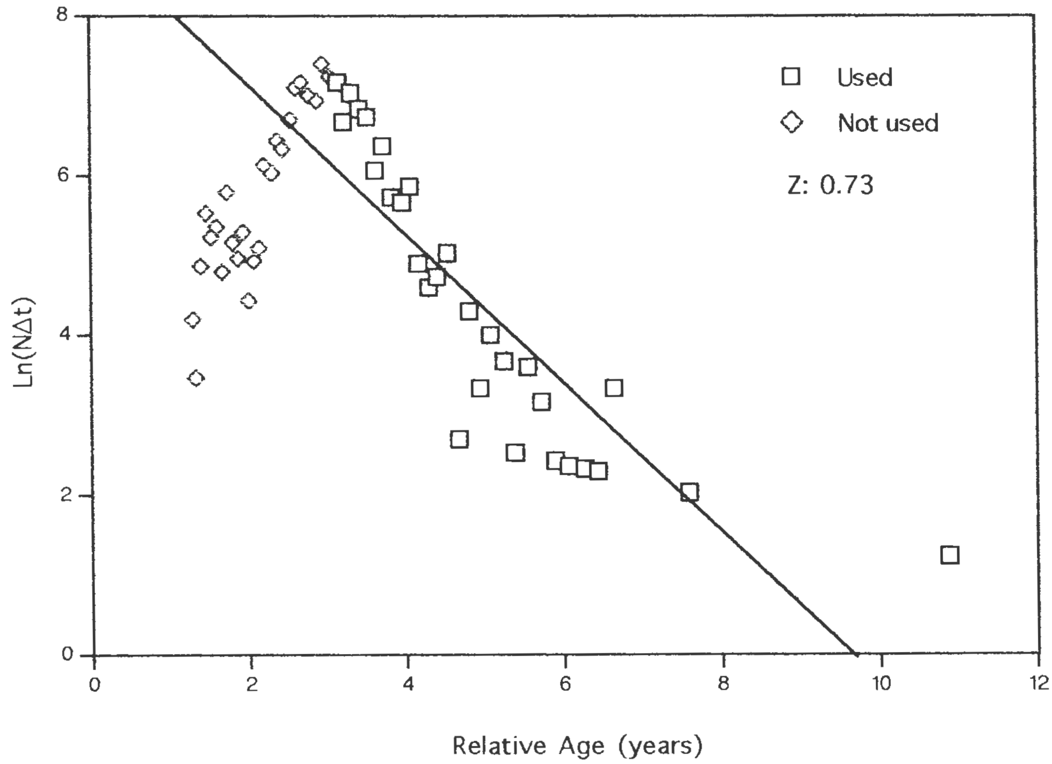


Figure 43: Length Converted Catch Curve for total sample, Z: 0.73.

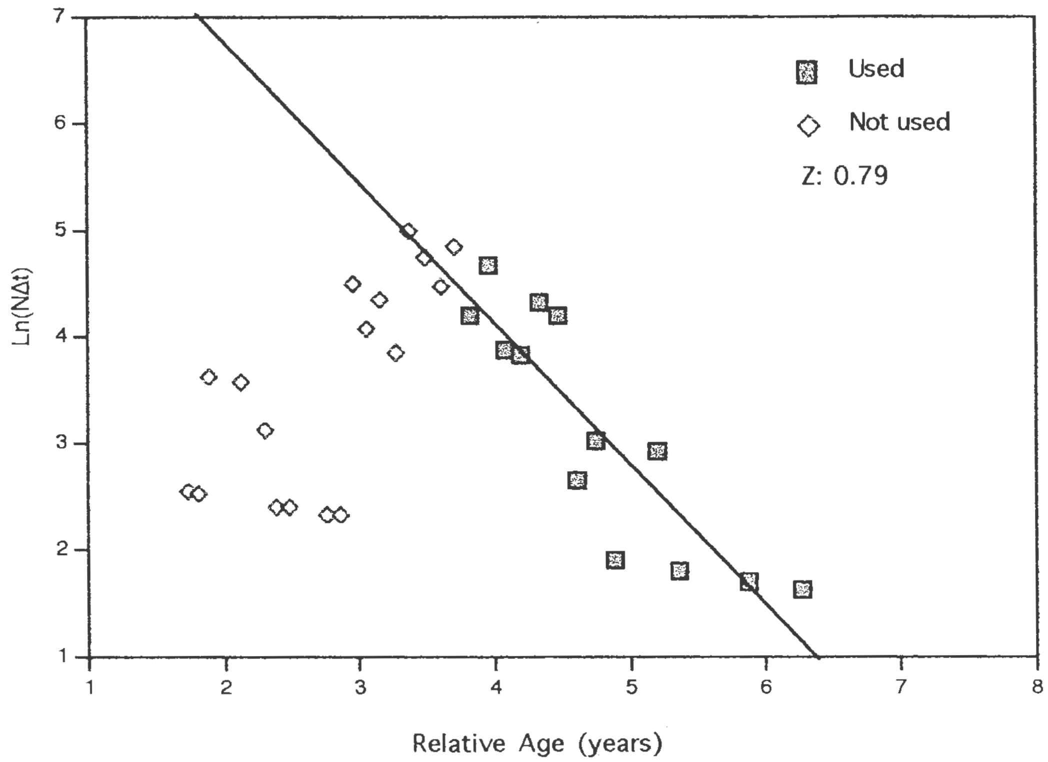


Figure 44: Length Converted Catch Curve for males, Z: 0.79.

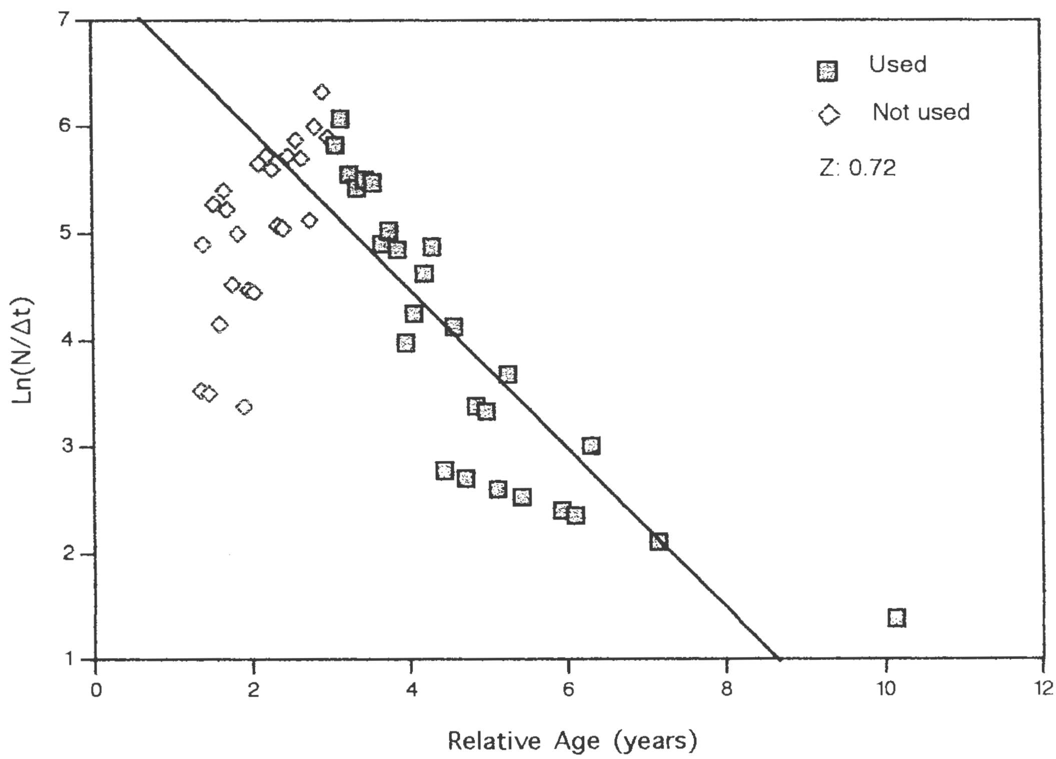


Figure 45: Length Converted Catch Curve for females, Z: 0.72.

9. DISCUSSION

9.1. The Area and Ecology

Snook migrate from East to West using the predominant E-W current Being a higher order carnivore, snook are commonly found in all the inshore waters of South Australia, but are more prevalent in the two gulfs and the West Coast. Few are landed in the South East, possibly due to the lack of shallow seagrass and kelps beds where their main prey is found.

9.2. The Fishery

Haul nets are replacing trolling as the preferred method of fishing, with significant increases in landed catches for the past four years (1989/90-1992/93), and the perception amongst fishers is that the species has been more abundant in recent years. This confirms the difficulty of using catch and effort data as a means of estimating the relative abundance for pelagic, migratory species (Laevastu and Favorite, 1988), and fluctuations in catches are most likely due to the spacial-temporal distribution of the species, and not to fluctuations in the stock abundance. CPUE has increased for the haul nets and decreased for the trollers since 1988/89. Trolling effort has increased considerably in the last year of data (1992/93). This could be due to fishers targeting snook because of poor southern calamary *(Sepioteuthis australis)* catches during that year (Jones, personal. communication, 1994).

9.3. Reproduction

Snook reproduce from late November to early February, possibly in offshore waters. Almost all females older than 2.4 years of age were mature (42 cm total length). From the data gathered it appears that the females have asynchronous ovaries, (ovaries in which oöcytes of all stages of development are present at the same time) and the species is a serial batch spawner.

When the spawning data is analysed, it becomes apparent that the species spawns only once a year, and only for a relative short period of approximately 12 weeks. This has important implications for future management of the fishery. Heavy target fishing during the spawning season could seriously affect the fishery, as recruitment would be affected.

The Gonosomatic Indices indicates that spawning may have occurred from early December. This gives a fair indication of when spawning occurred, but in itself should be used with caution. Cayre and Laloe (1986), and Yoshida (1964), found that the gonad index was not an accurate indicator of the later stages of gonad maturation.

Bell et al, (1992), cautioned against using GSI to identify whether spawning had occurred, or when it occurs, in any situation where it is not possible to collect representative samples, although he does not indicate what manifests a representative sample. However, from the data gathered it is clear that for this species, GSI with other indicators such as

Condition Index, can be used with confidence to indicate the time of spawning. The sharp decrease in the condition indices usually indicates a short spawning period (Bolger and Connolly, 1989). In this instance it assists in verifying the spawning season of the species.

The sexual maturity of 42 cm total length is an important parameter, as at present the minimum legal length is 36 cm. From the numbers of specimens less than 42 cm total length collected (N = 94, 10% of total samples), and from personal observation, this suggests that significant numbers of sexually immature fish could be caught, especially by the commercial power haul nets. It is difficult to determine the numbers taken in the haul nets as almost all fish under 40 cm total length are discarded, mainly due to low body weight and resultant low market value. This study has found however, that a considerable number of smaller sized fish down to 24 cm total length, are being taken in the 3 cm haul nets, with an L_c of 26.5 cm. From personal observation, all fish less than 42 cm that have been found in the haul nets (mostly gilled) have a very high mortality; almost all have been recovered dead. Sexually immature fish appear not to be as significant a problem with the trolling gear, with only a few caught.

Experiments have been done on mesh selectivity (Jones, 1982) for the commercial haul nets in South Australia, using a one cm pocket cover. The results were that for a 3 cm stretched mesh net, with garfish *(Hyporhamphus melanochir),* the 50% selectivity was 24 cm. With yellowfin whiting *(Sillago* *schomburgkii)* the results were a 50% selectivity of 15 cm. With King George whiting *(Sillaginodes punctata)* using a 5 cm haul net, and a 3 cm pocket cover, the 50% selectivity was 32 cm.

It is clear from the preceding, that mesh size, especially of the pocket, has an important role to play in regulating length at first capture and minimum legal length. The 50% selectivity of 26.5 cm for snook is certainly seems too small to sustain indefinitely, and the mesh sizes of the power haul nets requires review.

It is probable that the juveniles move from the nursery areas after approximately a year, and are then recruited into the adult stock; therefore the age at maturity (approx 2.4 yrs) does not seem to coincide with the age of recruitment.

Oöcyte diameters were used to assist in determining the spawning season and period. Oöcyte diameters have been used as an indication of maturation in other species of fish (de Sylva, 1973) although the use has been criticised (West, 1990). However the results of the Mean Oöcyte Diameters (MOD), the Gonosomatic Index, as well as the Condition Indices clearly indicate that spawning occurred over a period of approximately 12 weeks. It was concluded that the species is a spring/summer spawner.

Most of the large oöcyte sizes (>0.40-0.50 mm) were found in fish above 50 cm total length. Harris (1986) found that there was a significant effect of fish size to oöcyte size. Fulton

(1898), observed that there were comparatively few oöcytes in the intermediate sizes in large pelagic species and that this condition was associated with a rapid spawning period.

Development of the oöcytes is complex and the usefulness of oöcyte distribution in predicting the number of spawnings (West, 1990) is doubted and depends on the size classes used. It is apparent that attempting to determine the duration of the spawning season or likely number of clutches spawned from oöcyte size-frequency distribution alone is difficult to estimate.

The number of eggs produced for the females ranged from approximately 40,000 eggs for 2.4 year old fish to approximately 400,000 eggs for 7 to 11 year old fish. It was not possible to evaluate whether fish condition effected the fecundity of the females. Fecundity increased with fish length and weight, and this increase appears to be linear.

It was not determinable if spawning takes place in response to environmental factors such as increased day lengths, moon phases, water temperature (there is warmer sea surface temperature during the summer months in South Australia), tides or rainfall. Spawning activity could be related to increased food activity and prey. The snook actively prey on teleost species, as well as greasyback prawns and southern calamary.

The location and size of the spawning area has not been determined. The hypothesis advanced is that the species spawns in deeper water as is common with the other species in the Sphyraenidae family (de Sylva, 1973). There is no information about the larval and early life history of the species, and it is assumed that after a time the larvae move inshore to sheltered areas, and stay in this area feeding and growing, until a certain size, possibly pre-adult, is reached. However no fry and only a few small juveniles has been found in the estuaries or inshore areas of the two gulfs. What effect winds and sea surface temperature has on recruitment of the fry to the nursery area(s) is at present not known. It is possible that the species is not estuarine/mangrove dependent during the juvenile phase, but more research is required to confirm this. It is not known how tolerant the species is to low salinities or turbidity levels.

The short spawning period and the lack of fish on the fishing grounds indicates that spawning aggregations could occur for the species, with possible pre-spawning migration to the spawning grounds. Food availability may influence the number of fish breeding and shorten the spawning period. Further research is required to determine this.

Variation in sex ratio occur for the snook as well as other species in the family; the reason for this is not known, but could be due to pre-spawning separation and spacial segregation of the sexes, or greater vulnerability of females to trolling gear. This may vary with the various reproductive states of individuals. However there is no biological data to suggest or confirm this. There could be differential attraction of males and females to baits and lures, but more research is required. From studies done on other species in the family, considerable variation is also shown in the sex ratios (de Sylva, 1963; Lewis et al, 1983).

The monthly mean Weight/Length ratios of each sex is useful, and can assist in indicating the spawning of the species; it points to the males starting to milt from early December and the females starting to shed eggs shortly after this, from early January. These ratios indicate a spawning period slightly later than those obtained by the GSI and Condition Index, but is nevertheless still a useful tool in assisting the determination of spawning season.

9.4. Feeding and Movement

Of the fish identified in the stomachs, pilchard *(Sardinops neopilchardus)*, which was found in the Spencer Gulf around Whyalla and Port Lincoln during November and February was the most common species; the snook obviously actively preyed on the species during those, and probably other months when the pilchards were in the area. Southern sea garfish *(Hyporhamphus melanochir)*, was the next most common species, with small numbers of yellow-eye mullet *(Aldrichetta forsteri)* and weedy whiting *(Haletta semifasciata)*. Greasyback prawns (*Metapanaeopsis* species) were consumed during May-June and December-January.

Snook are opportunistic predators, preying on virtually any potential food source, and from the variety of species taken, feeds throughout the water column on both demersal (eg weedy whiting and Greasyback prawns), and pelagic species (eg pilchards, southern sea garfish and squid).

Not much can be determined from the feeding pattern, but it appears that the species goes off the feed during spawning, with relatively few stomachs containing contents during October and November and also in March.

Anecdotal evidence suggests that over the summer months the larger fish move from west to east, so that from the end of February only smaller sized fish are available to fishers. This could be a movement pattern linked to spawning, sea surface temperatures or winds. Tagging would be required to determine the seasonal movement of the species.

9.5. Growth

More smaller sized fish were found, with more pre-adults from February to April; this could be due to recruitment of juveniles from the nursery areas. 87% of the sampled commercial catch was in age classes 2 and 3 years.

From the length frequency distribution, it is apparent that generally females were larger than males. There is a higher natural mortality for the males possibly due to more effort used for spawning. Other factors such as protandrous hermaphroditism can only be speculated upon at this stage.

It appears that there are larger fish in northern Spencer Gulf (Bertoni 1992, 1993, 1994; unpublished data). Growth rates estimated for the two different fishing methods (haul net and troll) are not significantly different, which suggests that the estimates of L_∞ and K are reasonably accurate, and that the gear used by the two different methods is not overly selective. The L_∞ (97.4 cm) for combined sexes, is similar to a previous study (L_∞: 94.4 cm) and the K value (K: 0.230/year) obtained in this study is slightly less than that obtained from a previous study, but still realistic (K: 0.256/year, Bertoni, 1991). The Wetherall method virtually emulated the ELEFAN results (combined data) and the two methods gave a reasonably accurate indication of the L_∞ and K values.

The larger L_∞ of 98.0 cm for the females compared to the males (L_∞: 89.9 cm) were consistent with the size distributions of the commercial catch. The sex ratios, shorter life span and lower K values, indicates a different growth rate for the males.

Length weight data can be used to study fish condition and assume that heavier fish of a given length to be in better condition (Bolger and Connolly, 1989). Comparing the weight at length/age it appears that the condition of fish in 1993/94 are very similar to that of 1990/91, although the males are smaller for a given age.

9.6. Sagittal Otolith Results

According to Pawson (1990), in many fish species, there is a direct proportionality between otolith length and fish length. and one would expect a power function relationship to apply between otolith weight and fish length or fish weight (Boehlert, 1985; Gauldie, 1988). For the snook, it was determined that the otolith weight increased with the increasing length and weight of the fish and that there is a relationship.

Information that facilitates the interpretation of otolith structure is knowing when the incremental zones are formed. For temperate species, the wider opaque zones are usually deposited in spring/summer during a period of increasing growth occurring for a relatively short part of the year, and the narrower translucent zones in autumn/winter during a period of decreasing growth (Williams and Bedford, 1974, Fowler, 1994). The faster growth period is usually linked to warmer water temperature, feeding patterns, or reproductive cycles (Beckman and Wilson, 1994). From the results obtained in this study, the snook follows this pattern of depositing the opaque zone during spring/summer, and then depositing the translucent zones from February onwards.

Beckman and Wilson (1994) suggested that the formation of the opaque zones was generally better correlated with the increasing growth rates due to seasonal variation rather than the reproductive season. Due to lack of research data, there is no well-defined trends comparing the formation of the opaque zone to the timing of the spawning season.

There were only very few 0+ fish - this is probably due to the selectivity of the gear, as well as fishers discarding any fish below the minimum legal limit of 36 cm. From the sectioned otoliths opaque zone age classes given in Table 10 (page 68), it is evident that the larger age classes are found over the spring/summer months from October to February; this could be due to various reasons such as spawning season, or water temperature.

The FISHPARM results from the sectioned otoliths gave very similar results for the females and combined data when compared to the length frequency results using ELEFAN and Wetherall. It was not possible to confirm the different growth of the males with otoliths due to there being insufficient numbers in the larger age classes. In many species of teleosts there are differences in growth between the sexes (Six & Horton, 1976; Kimura et al, 1979; Johnson & Saloman, 1984, Fable et al, 1987; Fujiwawra & Hankin, 1988). Otolith growth results therefore complemented the ELEFAN and Wetherall results and the length frequency estimates, with no significant differences between the two methods for the females and combined data. The ELEFAN L_∞ and K results for the males is probably reasonably accurate considering the different growth rate.

9.7. Total Mortality

The males (Z = 1.035) have a higher total mortality than females (Z = 0.80). The total mortality is comparable with that obtained from previous data. Assuming that fishing mortality is the same for both sexes, this would indicate that females have a lower natural mortality and from the length frequency data it clear that more large females were found in the commercial catch. There is a general tendency in a fish population for natural mortality to increase with age and for males to have a higher mortality (Beverton and Holt, 1959). The males possibly put more effort into spawning, and this could result in the higher mortality. Females outnumbered males considerably in age classes 3^{+} years and older but were present in approximately equal numbers in the younger age classes.

10. CONCLUSION AND RECOMMENDATIONS

10.1. Extent of the snook resource off southern Australia

The extent of the resource is unknown. South Australia is at present the only State landing substantially commercial quantities of snook. There is a potential resource off Western Australia and Victoria, but due to the small numbers presently landed by the commercial sector, this is at present not known.

There is still uncertainty concerning the sustainability of higher catches, and more research is required to determine the yield per recruit and egg per recruit analysis as well as movement (through mark-recapture studies). Spawning areas needs to be defined, as well as nursery areas.

10.2. Possible management options for the snook resource.

The relatively short spawning season can imply that the species could be vulnerable to heavy target fishing during the spawning period, when the species possibly form spawning aggregations. The bias in the sex ratio of females to males landed also needs to be taken into consideration, as well as the higher mortality rates of the males.

The present minimum size limit of 36 cm could be sufficient in the short term. For the longer term, legislation could increase the minimum legal length to the length at sexual maturity of 42 cm total length. The dilemma lies with the aperture size of 3 cm of the haul nets, which is used to target garfish. This implies that significant numbers of immature/pre-adults snook will always be taken by the haul nets and will always be vulnerable to commercial fishing. According to Walker (1990), the minimum legal limit set at the length at first maturity will protect the breeding stock.

There is great controversy and resentment between commercial haul netters and recreational fishers in South Australia as there is a perception that haul netters take relatively large quantities of fish (including small and undersized fish). This view is reinforced by the fact that the netters are required to operate in water depths of 5 metres or less, fish in many areas which are frequented by recreational fishers, and are readily observed by them. As well, there are concerns about benthos damage caused by the nets to seagrass beds.

At present permanent and seasonal net closures (for commercial and recreational netters) are used in certain areas of the two Gulfs to protect nursery and juvenile areas of important commercial species such as King George whiting *(Sillaginodes punctata)*. This has been mainly due to pressure from recreational and commercial line fishers. It should be noted that there are 6,155 registered recreational nets in South Australia for used in marine waters (Supplementary Green Paper, 1991). These netters catch mainly tommy rough *(Arripis georgianus)* and mullet *(Aldrichetta forsteri)* with small quantities of yellowfin whiting *(Sillago schomburgkii)* and King George whiting *(Sillaginodes punctata)* taken. No new recreational net licences are presently being issued.

What is required are measures that will maintain the proportion of catches between the haul netters and recreational fishers. Individual transferable quotas (ITQ's) had been recommended in a discussion paper published by the

South Australian Department of Fisheries (Supplementary Green Paper, 1991), but no further action has been taken on this, as the haul net problem is a politically sensitive issue.

10.3. Future Development of the snook fishery

The snook fishery is a supportive fishery with only small economic value when compared to the King George whiting and garfish fishery. Commercial fishers target the species when King George whiting and garfish catches are poor (Bertoni, 1993). Snook is undervalued, and is a price taker, and more marketing as well as value adding is required to exploit the full potential of the species. With more demand, higher prices could result in better return for the fishers. If larger catches can be sustained, then the fishery could be developed further. The flesh is excellent smoked and this is an option that could be looked at.